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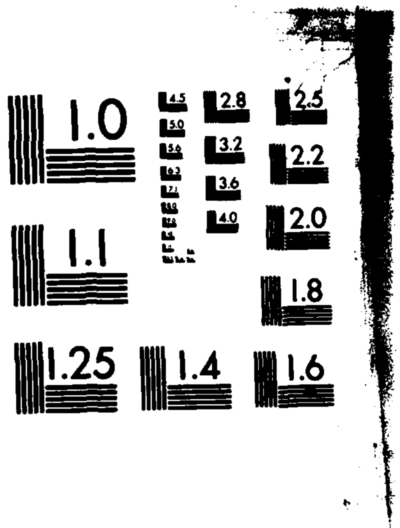
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Propellant Nonlinear Constitutive Theory Extension: Preliminary Results

August 1983

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prepared for the: **Air Force Rocket Propulsion Laboratory**

Air Force Space Technology Center
Space Division, Air Force Systems Command
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California 93523

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NOTICES

FOREWORD

This report was submitted by United Technologies Corporation/Chemical Systems Division, 1050 E. Arques Avenue, Sunnyvale CA 94086 under Contract F04611-80-C-0052, Job Order No. 2307M1EB with the Air Force Rocket Propulsion Laboratory, Edwards AFB CA 93523. This Special Technical Report is approved for release and pulication in accordance with the distribution statement on the cover and in the DD Form 1473.

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17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Strain	two-dimensional	straining-cooling	failure
Stress	three-dimensional	viscoelastic	time-dependent
Modulus	isothermal	nonlinear	elastic
Uniaxial	nonisothermal	linear	damage
Biaxial	constitutive	fracture	healing

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report details the technical effort put forth by CSD and its subcontractors during the first three phases of this program for propellant nonlinear constitutive theory extension. This includes the Phase I preliminary study in which the Quinlan theory was critiqued, alternate approaches were studied and detailed research planning accomplished. Also included are the detailed experimental evaluations of propellant during Phases II and III, the uniaxial/isothermal investigation and the two-dimensional variable temperature investigation. Detailed subcontractor theoretical development and predictions

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are presented.

This special technical report on Contract No. F04611-80-C-0052 consists of a summary of the Phase II and III laboratory propellant evaluation for UTP-3001 and UTP-19,360B propellants. The detailed experimental results were distributed in Data Packages A through G to all project personnel. Additional details are given in Section 1.0.

In performing the work required for the program, Chemical Systems Division (CSD) employed under subcontract the services of five scientists of national reputation: Drs. M. Quinlan, M. E. Gurtin, W. L. Hufferd, R. Wool, and R. A. Schapery. The program effort combined the comprehensive experience and specialized test capabilities of CSD in solid propellant mechanical properties with the theoretical expertise of these scientists. In addition, Dr. J. E. Fitzgerald was retained as a consultant to participate in the periodic technical reviews of the program status.

CONTENTS

CONTENTS (Cont'd)

ILLUSTRATIONS

ILLUSTRATIONS (Cont'd)

ILLUSTRATIONS (Cont'd)

ILLUSTRATIONS (Cont'd)

ILLUSTRATIONS (Cont'd)

ILLUSTRATIONS (Cont'd)

ILLUSTRATIONS (Cont'd)

ILLUSTRATIONS (Cont'd)

TABLES

TABLES (Cont'd)

1.0 PROGRAM OBJECTIVES AND OVERVIEW

The objective of the Propellant Nonlinear Constitutive Theory Extension Program is to develop and demonstrate an accurate and usable nonlinear thermal-mechanical constitutive law for solid rocket propellants. The program has been conducted through three phases of a four phase project. These four phases are summarized below:

Phase I - Preliminary Study

A variety of nonlinear theories were considered and five methods were selected for further study.

- Modified Swanson Theory
- Russian - (Hufferd) Theory
- Schapery Theory
- Gurtin Theory
- Quinlan Theory.

Dr. Richard Wool presented a review of available micro-mechanics theories which could be considered for inclusion within the nonlinear constitutive theories.

Phase II - Uniaxial Isothermal Investigation

A series of unaxial tests were conducted with two materials - a PBAN and an HTPB propellant. The data was fit to each of the nonlinear theories. Then the material constants derived for each analytic method were used in a predictive calculation of a complex laboratory test history which included some typical long time rocket motor mechanical bonding sequences. A review of the analytic methods and predictive results showed that all of the theories could be adapted to give better correlations with realistic motor loading conditions. Other test histories were also suggested that would permit more direct evaluation of the pertinent nonlinear material behavior required for each theory. Numerical difficulties were encountered with some theories and refinements were determined

that would hopefully eliminate these problems. All five theories were considered acceptable and were to be further developed in the next phase.

Phase III - Two-Dimensional and Variable Temperature Investigation

The analytic and numerical improvements were made with each theory. These refined methods were then evaluated with the test data from phase II plus the additional recommended tests from the phase II review meetings. Most of the analytic methods looked very good with the final refinements. This effort, using the latest data, used most of the scheduled time for this phase. In addition to the suggested uniaxial mechanical tests, a variety of shear, biaxial and uniaxial (some with simultaneous thermal and mechanical loading) tests were conducted with some very complex load histories. This latest test data was only considered in a preliminary way since the theory modifications were very exstensive.

Phase IV - Three Dimensional Investigation (Not started)

The additional laboratory data developed in phase III plus some instrumented structural test vehicle data will be used with the various nonlinear constitutive theories. One or more selected theories will be determined and the computer codes will be installed and checked out on the Air Force Rocket Propulsion Laboratory's computer.

The program logic chart relating each of the phases and their respective tasks is presented in Figure 1.

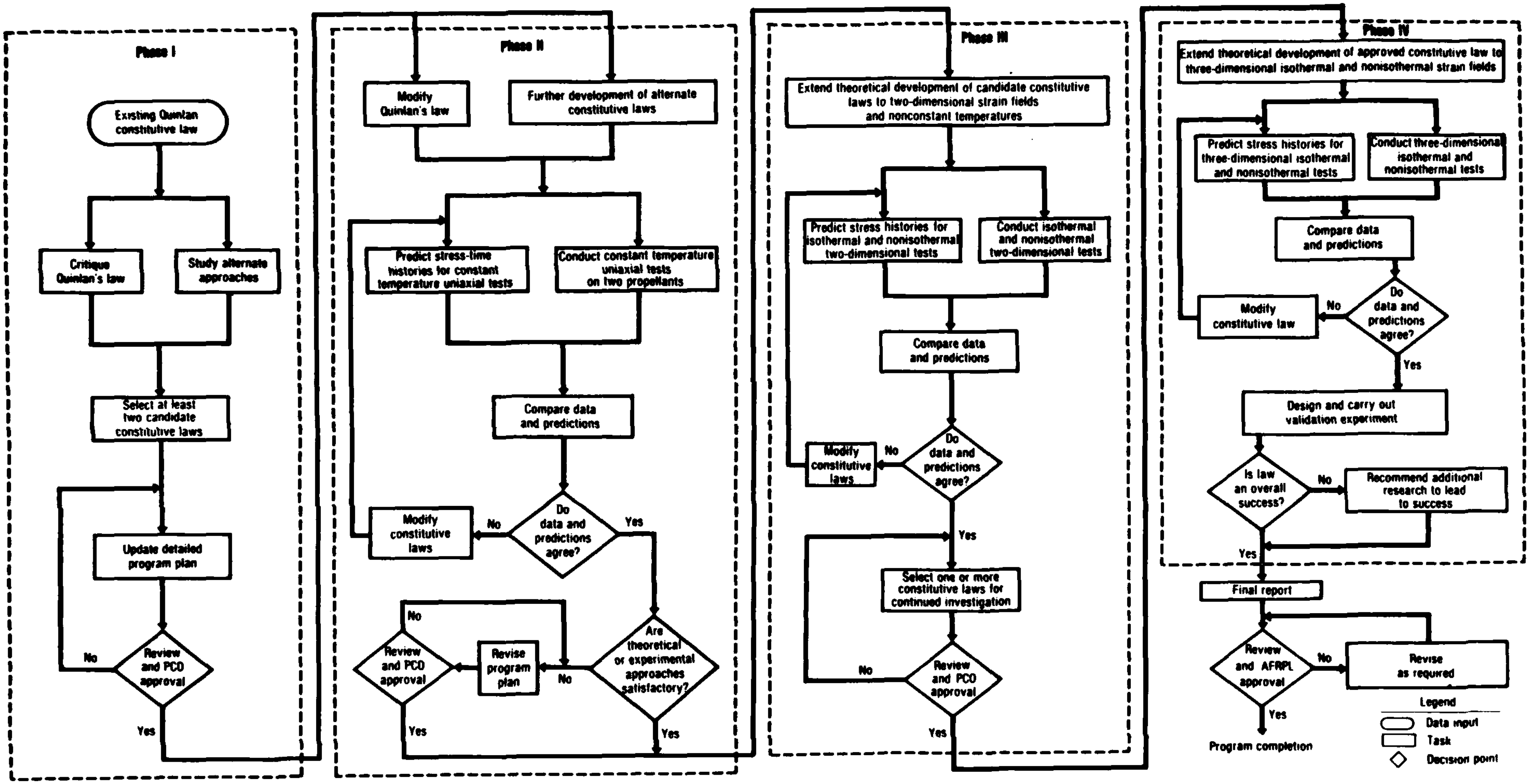

Figure 1. Program Logic

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2.0 TASK DESCRIPTION

2.1 PHASE I - PRELIMINARY STUDY

The objective of phase I was to critique the Quinlan theory, propose at least one alternate approach to the constitutive law solution, and make detailed research plans for evaluating and modifying the candidate constitutive law approaches.

2.2 PHASE II - UNIAXIAL/ISOTHERMAL INVESTIGATION

The objective of phase II was to carry out modifications to Quinlan's law and to do theoretical development of the other candidate constitutive laws. These laws were used to make stress-time predictions for uniaxial/isothermal tests. Concurrently, actual uniaxial/isothermal tests were conducted in the laboratory. A comparison of the predictions and actual data was then made, and the theoretical and experimental approaches were evaluated.

2.3 PHASE III - TWO-DIMENSIONAL AND VARIABLE TEMPERATURE INVESTIGATION

The objective of phase III was to extend the theoretical development of the candidate constitutive laws to two-dimensional and variable temperature tests. Stress-time predictions were made concurrently with actual testing in the laboratory. A comparison of predictions and actual data was made and two constitutive law candidates were selected for further investigation from those results.

2.4 PHASE IV - THREE-DIMENSIONAL INVESTIGATION

The objective of the final phase is to extend the theoretical development of the candidate constitutive laws to three-dimensional and variable temperature history tests. Concurrently, three-dimensional, variable temperature laboratory tests are to be conducted. Data and predictions will be compared and any final modifications to the constitutive law made. A validation experiment is to be conducted, and stress-time predictions made with the finalized version of the nonlinear constitutive law. A final assessment of the overall success of the new law will be made and recommendations will be presented for further avenues of research. Recommendations for utilizing the new law in existing solid rocket motor structural analysis techniques will also be made.

3.0 LABORATORY TESTS, RESULTS, AND SUMMARY

The laboratory testing was divided into the categories of uniaxial/isothermal, two-dimensional and variable temperature, and three-dimensional investigations.

The two propellants selected for the program were (1) a PBAN currently being used in the first stage of the Titan missile system (UTP-3001-750/7768) and (2) a HTPB propellant developed for the IUS motor (UTP-19,360B-400/1777). The first numbers are the propellant designation, the next the mixer size, and the last a batch number.

In each of the uniaxial or biaxial groups, a specific test of each type was selected to show the test details in graphic and tabular form. While tests were run on both propellants, only one is shown. The details of test temperatures and rates are discussed with each test type.

3.1 UNIAXIAL/ISOTHERMAL INVESTIGATION

Testing uniaxial specimens of UTP-3001 and UTP-19,360B propellants, in phase II of the contract, was done for the nondamaged material as indicated in Figure 2 and for damaged material per Figures 3 and 4. Most of the tests were run with 1/2 x 1/2 x 6-in. bars with redwood end tabs. The exceptions were stress endurance (test 2) and constant rate (comparison to test No. 4) data were obtained with JANNAF Class B specimens.[1] The details of the individual test types are discussed in subsections below.

The uniaxial bars were machined from redwood boxes of propellant. The redwood was sealed then lined in the same manner as a rocket motor. After a partial cure of the liner, propellant was cast in the box and the system cured to provide a good bond to the redwood end tabs. The redwood box assembly and finished specimen are shown in Figure 5. After the specimen is mill finished,

Reference 1 - Solid Propellant Mechanical Behavior Manual, CPIA Publication No. 21, Section 4.3.2

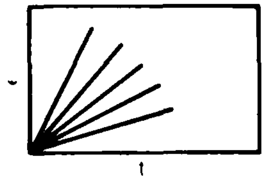
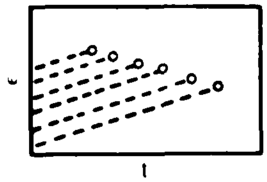
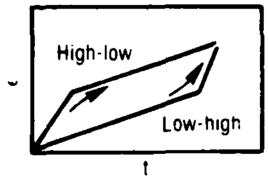
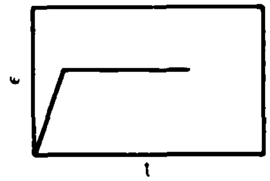
Test No.	Test Description	Temperature, °F	Pressure, psig	Rate, in./min	Strain, %	Experimental Effects	Strain History
1	Constant rate	70 120 40	0 0 0	0.001 • 10	To failure	Time and rate temperature sample type	
2	Stress endurance	70 120 40	0 0	— —	To failure	Time and temperature	
3	Multirate	70	0	0.1-1 1.0 — 0.1	12 12	Rate change	
4	Stress relaxation	70 120 40 23	0 0 0 0	1 1 1 1	3 3 3 3	Temperature	
Note: Nominal tests were run with three samples per set							Legend: ϵ = strain t = time

Figure 2. Uniaxial Isothermal Nondamaged Tests

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a 1/8 in. hole is drilled on the center line of each end tab for attachment purposes. (Attachment fixtures are shown in Figure 16).

Due to the enormous test load compared to the available time, both calendar and contract wise, the decision was made to run all tests on six-channel testers. Both the Chemical Systems Division (CSD) manufactured six-channel tester and a modified Instron were used in conjunction with a Hewlett-Packard computer to collect digitized data for the tests. (See Appendix A details on the automated data reduction system). While the CSD tester was equipped with an oscillograph as backup for relatively short duration tests, the modified Instron had no backup. In instances where a power surge occurred, the data were lost and the test had to be rerun.

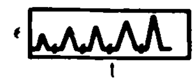
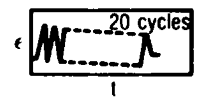
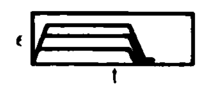
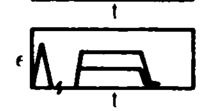
		Damage Cycle					Test				Strain Cycle
Test No.	Test Description	Temperature, °F	Pressure, psi	Rate, in./min	Strain, %	Remarks	Temperature, °F	Pressure, psi	Rate, in./min	Strain, %	
5	Multiple loading with rest periods; step cycle	70	0	0.1, 1, 10	3	30-min hold between cycles	70	0	0.1, 1, 10	3 to 12	
6	Creep	70, 120, 40	0	1	1/4, 1/2, ~maximum	3-hr creep periods; first step only for 120 and 40°F	70	0	1	1/4, 1/2, ~maximum	
7	Cyclic loading	70	0	1	4, 8, 12	20 cycles; return to zero stress and monitor E recovery	70	0	1	4, 8, 12	
8	24-hr relaxation	70	0	20	4, 8, 12	Monitor the unload	70	0	1	4, 8, 12	
9	Predamage relaxation (1 hr)	70	0	0.1	6, 12	30-min hold between loading; monitor unload	70	0	20, 1	3, 4, 8	
10	Complex multiple load	70	0	0.1, 1, 5	12, 8, 4	High strain followed by low strain; return to zero stress and monitor strain	70	0	0.1, 1, 5	12, 8, 4	
Note Nominal tests were run with three samples per set											Legend: ϵ = strain, t = time

Figure 3. Uniaxial/Isothermal Damaged Tests

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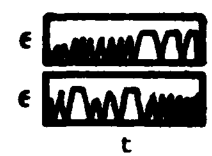
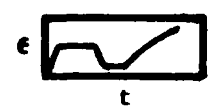
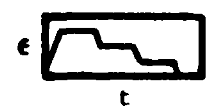
Test	Test Description	Damage Cycle / Test	Strain Cycle
11	Quinlan complex history	Single samples clamped in rigid Instron jaws were run on UTP-3001 and UTP-19,360B. In returning to zero strain the samples were put into compression. Data are reported in "Data Package F".	
12	Similitude	Similitude tests were run with 6-in. bar samples of UTP-3001 and UTP-19,360B. Data are reported in "Data Package E" and the September meeting handout.	
13	Three step relaxation	Short and long time tests were run with 6-in. bar samples of UTP-3001 and UTP-19,360B. Data are reported in "Data Package E" and the September meeting handout.	
Note: Nominal tests were run with three samples per set			Legend: ϵ = strain, t = time

Figure 4. Uniaxial/Isothermal Damaged Propellant Tests

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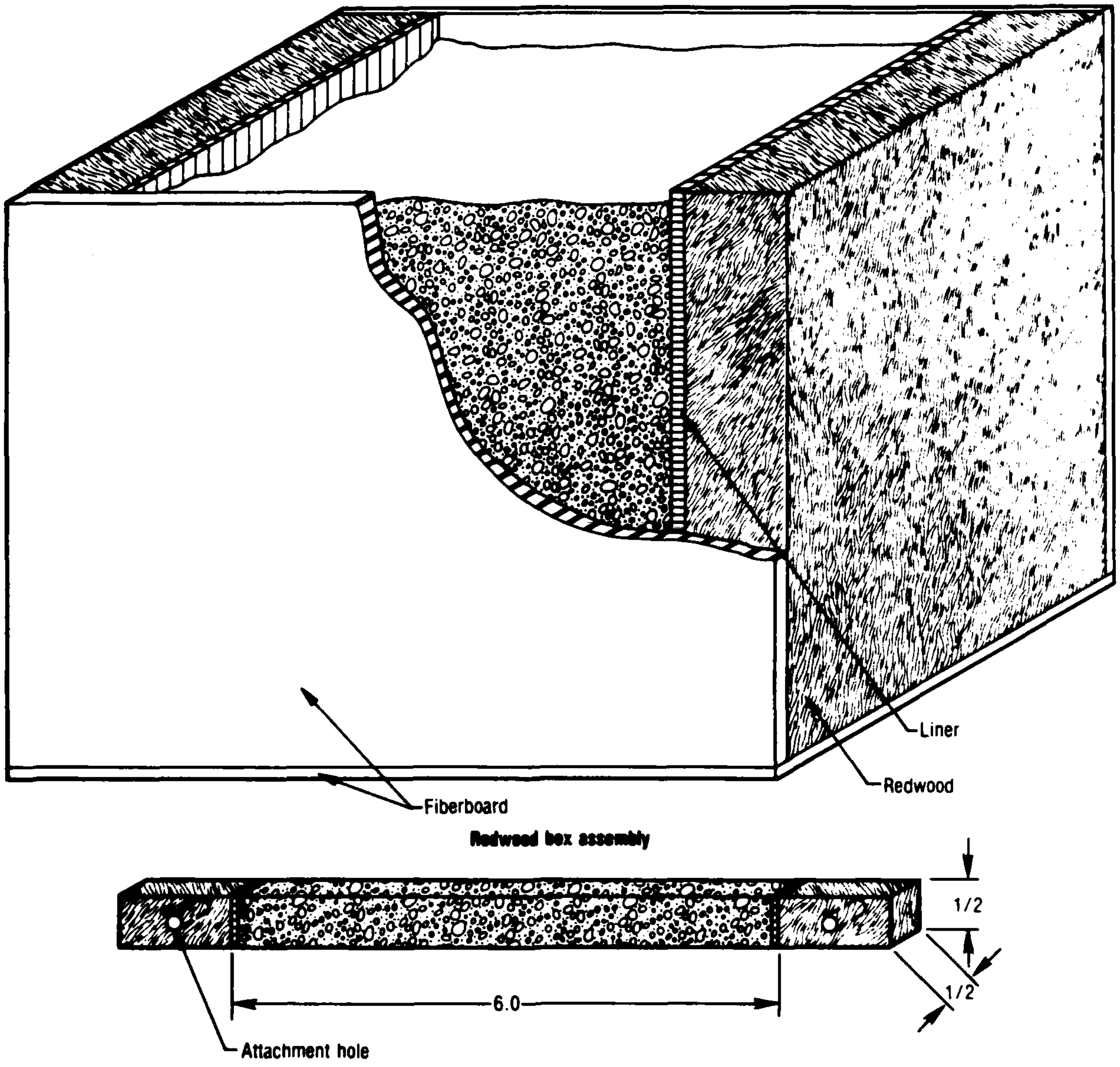

Figure 5. Uniaxial Bar Specimen

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The attachment linkages on both testers were such that the specimens could not be put into compression when the crosshead was returned to an equivalent zero strain position. The strain measurement was done with a linear potentiometer attached to the crosshead; consequently, the data had to be modified to reflect the propellant strain relaxation behavior after the stress had returned to zero (free hanging specimen).

Strain relaxation was measured on samples in some of the tests during the final unload cycle. Cathetometer measurements were made periodically and strain versus time data were plotted. These data were used to estimate the relaxation behavior on cyclic tests where there was insufficient time for measurements.

A data modification was made to estimate the peak or minimum stress and strain points, which were not recorded by the digitized data acquisition system. The sampling rate limited the crosshead rate that could be used and still obtain enough points to adequately define a ramp. The available computer memory also influenced the sampling rate in some of the long tests.

3.1.1 Constant Rate Test No. 1

Uniaxial constant rate tests to failure were run on 6-in. bars of UTP-3001 and UTP-19,360B. The 70°F tests were at crosshead rates of 10, 1, 0.1, 0.01, and 0.001 in./min. while 40 and 120°F tests were at 10, 1, and 0.1 in./min. A typical load-time curve is shown in Figure 6 for the UTP-3001 at 75°F and 10 in./min., and tabular data are given in Table 1. Because of the computer

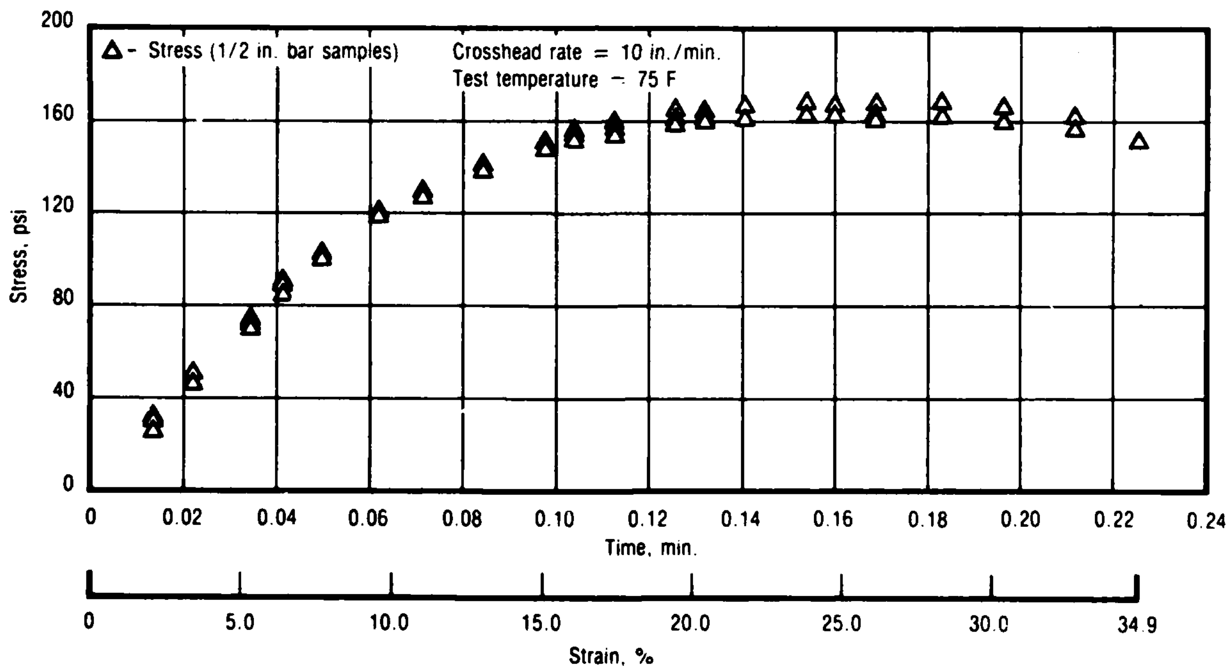

Figure 6. Test No. 1 - Straining to Failure for UTP-3001 750/7768

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TABLE 1. 1/2-IN. BAR STRAINING TO FAILURE

PROPELLANT: UTP 3001 750/7768
REQUESTOR: Carlton
WOR:

DATE: 4/21/81
OPERATOR: JWD

DEFINITIONS:

Time	= Time From Start of Test (min)
σ	= Stress (psi)
ε	= Strain (%)
E	= Secant Modulus (psi)
T(air)	= Test Air Temperature (F)
T(prop)	= Test Propellant Temperature (F)

RELATIONSHIPS:
σ = Force/Area
ε = Sample Extension/Length

NOMINAL VALUES:
Test Temp = 75 F
Gage Length = 6.10 in
XHD Rate = 10 in/min

CALIBRATION DATA:

	SAMPLE 1	2	3	4
Cal Wt = 10.0 lbs				
Load Cal (lbs/volts)	-4.24	-3.11	-3.33	-2.70
Offset (volts)	-0.04	-0.05	-0.06	-0.06
Pot Cal (in/volts) =	1.33			
Temp (F) =	73.9			
AREAS (sq in):	0.252	0.250	0.249	0.250

SECANT MODULUS (psi):

Time	T(prop)	T(air)	Strain	Sample 1	Sample 2	Sample 3	Sample 4	Avg	St Dev
1.3500E-02			1.72	1520.92	1788.15	1893.57	1826.01	1757.16	94.351
2.1967E-02			2.99	1606.31	1760.60	1782.09	1737.62	1721.65	45.612
3.4567E-02			5.03	1507.81	1453.28	1498.36	1553.68	1503.28	23.769
4.1517E-02			6.24	1442.01	1537.49	1508.44	1520.54	1502.12	24.137
4.9858E-02			7.65	1409.10	1458.85	1421.10	1450.73	1434.94	13.665
6.2217E-02			9.66	1349.83	1372.40	1340.12	1367.11	1357.36	8.667
7.1442E-02			11.13	1287.58	1297.13	1269.25	1285.44	1284.85	6.682
8.4617E-02			13.05	1220.62	1224.03	1199.75	1215.61	1215.00	6.202
9.7825E-02			15.04	1153.64	1147.70	1126.31		1142.55	10.163
1.0396E-01			16.03	1124.75	1107.11	1094.29		1108.72	10.815
1.1265E-01			17.43	1073.94	1052.37	1039.79		1055.37	12.210
1.2580E-01			19.44	1005.20	980.02	972.79		986.01	12.030
1.3197E-01			20.33	969.81	949.64	942.63		954.02	9.977
1.4060E-01			21.60	933.66	909.50	906.09		916.42	10.626
1.5389E-01			23.59	876.72	851.44	849.93		859.37	10.642
1.5993E-01			24.39	852.16	827.64	823.34		834.38	10.995
1.6873E-01			25.84	814.05	788.76	779.84		794.22	12.546
1.8298E-01			28.19	760.02	733.02			746.52	19.093
1.9627E-01			30.30	711.01	683.14			697.08	19.709
2.1155E-01			32.71	653.60	631.85			642.73	15.379
2.2533E-01			34.94		582.66				

data sampling rate, the 10-in./min. tests were run one propellant at a time. Sample 4 (Table 1) shows the load cell reached the limit of its adjustment so did not record the specimen failure. The 6-in. bar specimens always fail below what would be obtained from JANNAF specimens. Since response properties are what is of interest, particularly in the small strain region, the uniform cross sectional area specimen does what it is supposed to do. The continual changing effective gage length of the JANNAF dogbone is avoided.

These data were also reduced to secant modulus ($\lambda\sigma/\epsilon$) as shown in Figure 7. The data are compared to the stress relaxation modulus from test No. 4 later.

3.1.2 Uniaxial Stress Endurance Test No. 2

Stress endurance tests were run on the two propellants using JANNAF Class B dogbones. The ultimate failure properties were of importance in this test rather than small strain response hence the dogbones. This is a constant load test with plastic extensometer to monitor the strain increase with time (also known as a creep test). They were run at 23, 70, and 120°F. The data shifted

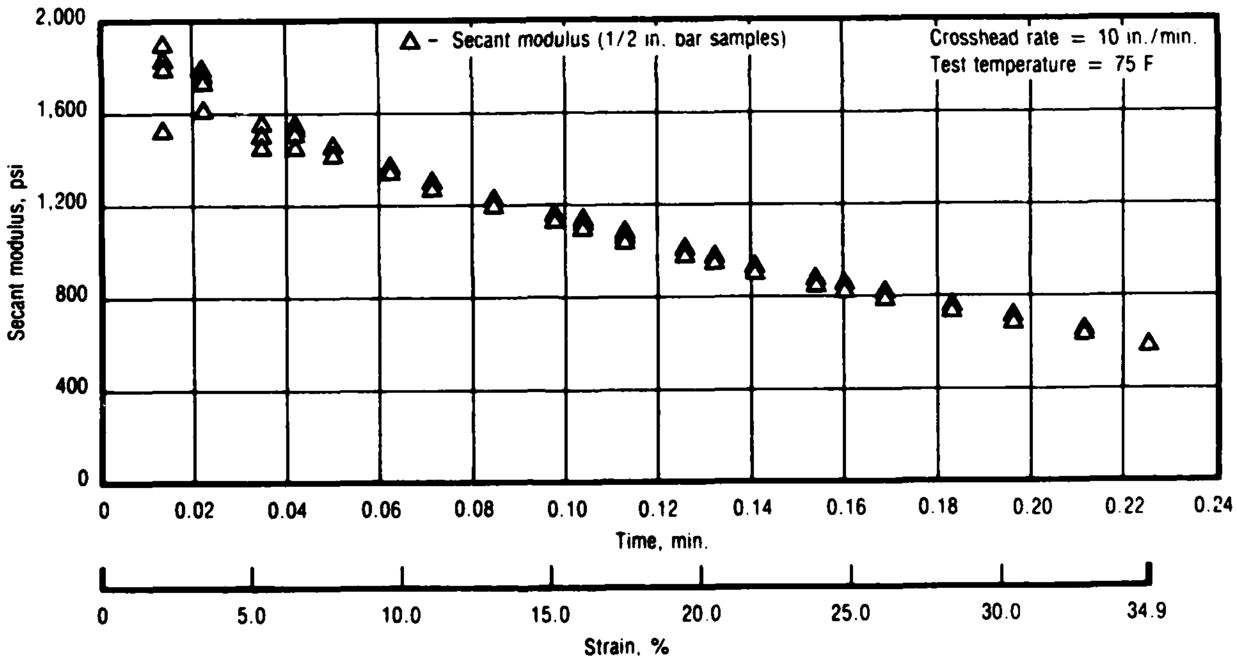

Figure 7. Test No. 1 - Secant Modulus for UTP-3001 750/7768

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to a master endurance curve as shown in Figure 8 for UTP-19,360B with typical 70°F data given in Table 2. The strain creep effect on stress is shown in Figure 9 where the engineering stress (F/A_o) is multiplied by the extension ratio ($1+\epsilon$) to account for the sample's necking down. The secant modulus ($\lambda\sigma/\epsilon$) for the 70°F data are shown in Figure 10 and data are given in Table 3. This same type of data were generated for UTP-3001.

3.1.3 Multirate Test No. 3

Constant rate tests were run on the two propellants and the rate was changed in the middle of the test. Because of the different response for the high-low compared to the low-high, an example of both is given. The test was included with the nondamaged tests because there was no rest or reversal in the crosshead direction. The first leg of the test could be considered the damage. The 1.0 to 0.1 in./min. rate change is shown in Figure 11 for UTP-19,360B and the 0.1 to 1.0 in./min. is shown in Figure 12. The corresponding data for the first sample of each group are given in Table 4 and 5, respectively.

3.1.4 Stress Relaxation Modulus Test No. 4

The stress relaxation modulus tests were run at a nominal 3% strain using 1/2 x 1/2 x 6-in. samples of propellant bonded to redwood end tabs for both propellants. The samples were loaded to 3% strain at a crosshead rate of 1 in./min. for temperatures of 20, 43, 73, and 122°F. The load was monitored with time. Strain was determined by cathetometer measurements on the samples. The relaxation modulus (E_R) was then calculated at specific time intervals by the following equation:

$$E_R = \frac{F}{A_o} \frac{\lambda}{\epsilon}$$

where F = force as measured by the load cell

A_o = initial area

$\lambda = 1 + \epsilon$

ϵ = strain

The master stress relaxation modulus data for UTP-3001 are presented in Figure 13 and typical data at 73°F are given in Table 6.

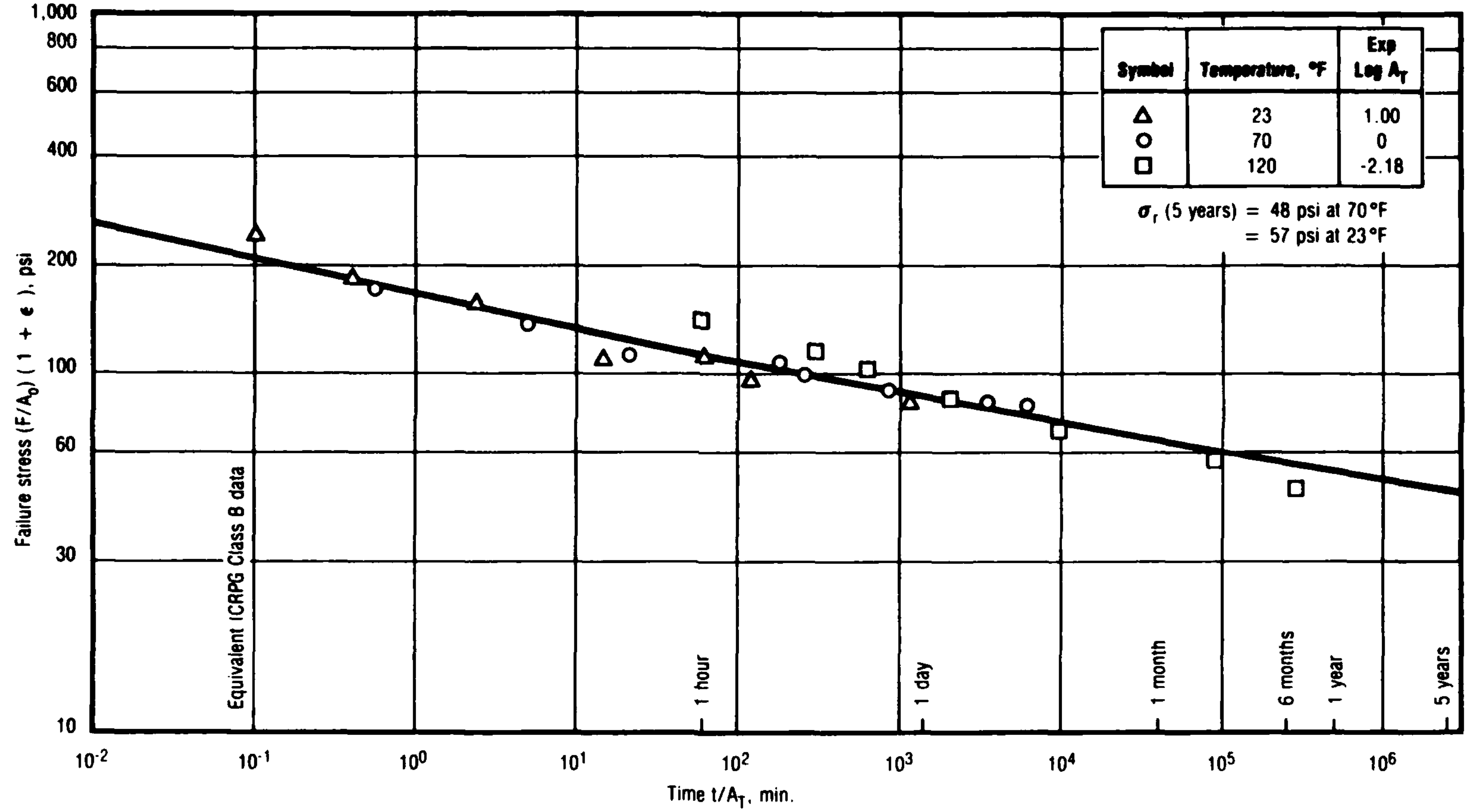

Figure 8. Test No. 2 - Master Uniaxial Stress Endurance Curve for UTP-19,360B-400/1777

28388

TABLE 2. TEST NO. 2 - UTP-19,360B 400/1777 CONSTANT ENDURANCE TEST

REQUESTOR: Carlton,Francis
OPERATOR: kg
TEST DATE: 3-23-81
WOR: 5013-251-0501
TEST TEMP = 73 F

THE DATA REDUCTION CONSISTS of 2 LEAST SQUARE FITS: ln(t) vs ln(σ) and ln(t) vs ln(ε)

t,ε	= FAILURE TIME and STRAIN(EXPERIMENTALLY DETERMINED)
σ	= CORRECTED FAILURE STRESS: (1+ε)F/A
LS	= LEAST SQUARE FAILURE VALUES at the EXPERIMENTAL FAILURE TIME
Δ	= EXPERIMENTAL MINUS LEAST SQUARE VALUES
Ao,A1,r	= INTERCEPT,SLOPE and CORRELATION COEFFICIENT of LEAST SQUARES LINE
S(E),S(A1),S(Ao)	= STANDARD ERRORS of ESTIMATE,SLOPE and INTERCEPT
.1min......5year	= LEAST SQUARE FAILURE VALUES at THESE FAILURE TIMES

AREA(in²)	t (min)	σ(psi)	LSσ(psi)	VE(psi)	ε (%)	LSε(%)	Δε (%)	
0.105	5.00	137.63	136.63	1.01	61.00	59.21	1.79	G.B.
0.104	[illegible]	171.87	163.88	[illegible]	64.00	[illegible]	[illegible]	G.B.
0.179	21.00	111.02	121.79	-10.77	50.00	56.77	-6.77	G.B.
0.102	246.00	98.02	99.97	-1.95	56.00	52.81	3.19	G.B.
0.100	6006.00	80.57	77.34	3.23	47.00	48.06	-1.06	G.B.
0.177	833.00	88.84	90.69	-1.85	50.00	50.75	-0.75	G.B.
0.103	176.60	106.52	102.69	3.83	57.00	53.33	3.67	G.B.

	Ao	A1	r	S(E)	S(A1)	S(Ao)	1 min	1 day	1 year	5 year
σ:	5.0462	-0.0801	-0.9815	0.0543	0.0070	0.0365	186.91	86.80	54.11	47.56
ε:	4.1283	-0.0294	-0.8171	0.0720	0.0093	0.0483	66.41	50.14	42.17	40.22

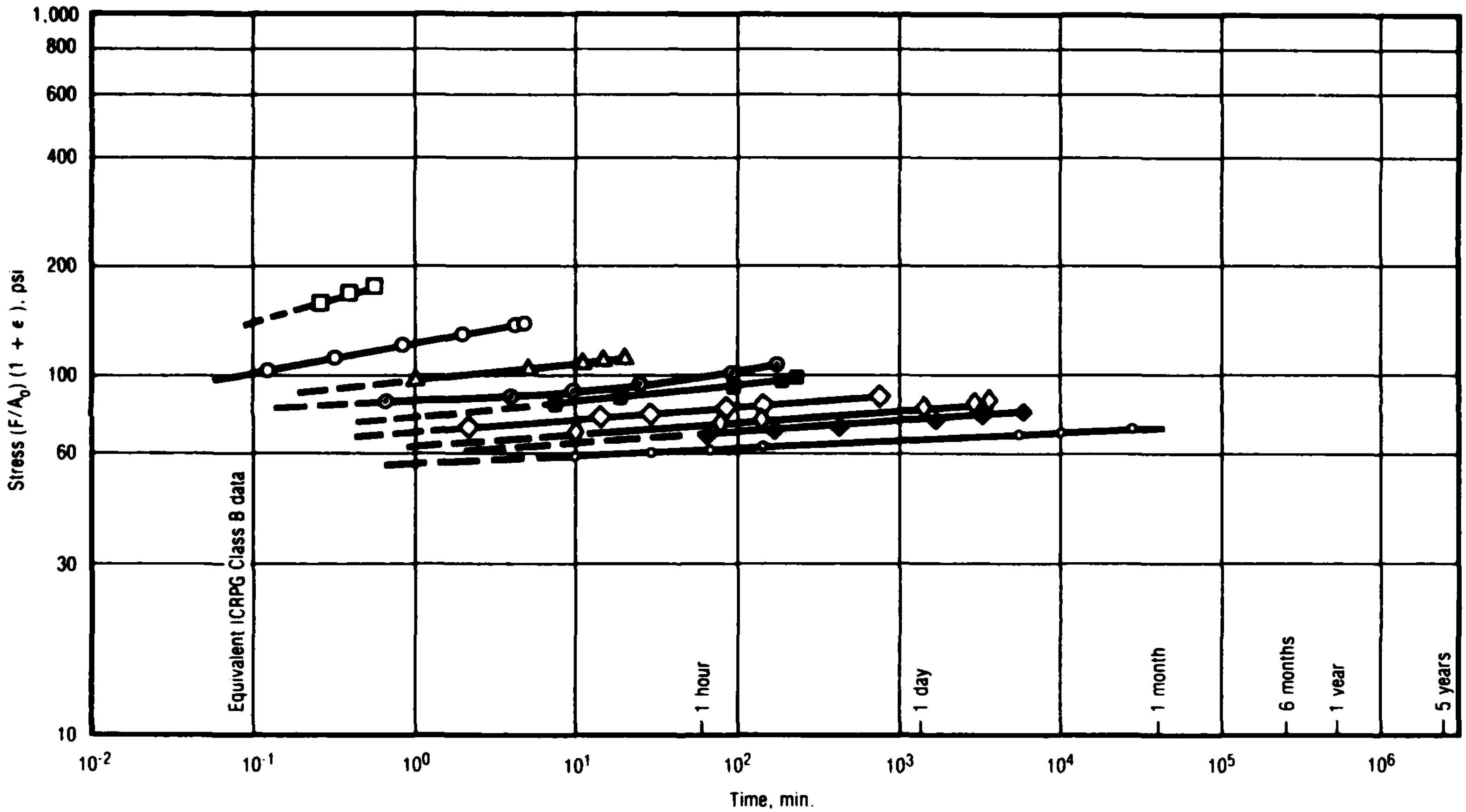

Figure 9. Test No. 2 - Uniaxial Stress Endurance Creep Behavior UTP-19,360B-400/1777 at 70°F
28389

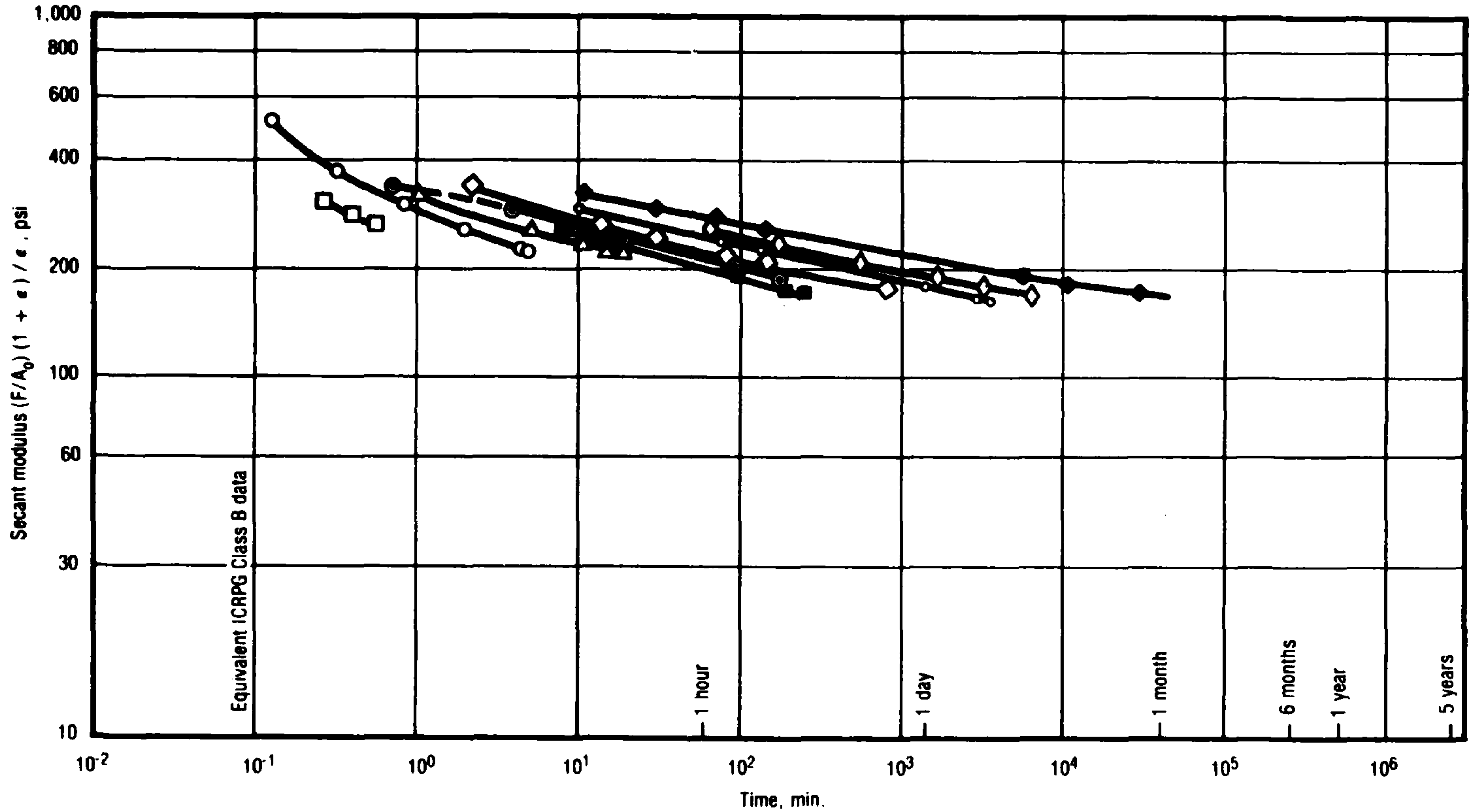

Figure 10. Test No. 2 - Uniaxial Stress Endurance Creep Secant Modulus Behavior for UTP-19,360B-400/1777 at 70°F

28390

TABLE 3. TEST NO. 2 - UNIAXIAL STRESS ENDURANCE CREEP BEHAVIOR FOR UTP-19,360B-400/1777 at 70°F

(SHEET 1 OF 2)

T8706

Temperature, F	Sample	Time, min.	Strain, %	Load, g	Area, in.^{2}	Stress (F/A), psi	$\lambda\sigma$, psi	Secant Modulus ($\lambda\sigma/\epsilon$), psi
70	1	0.13	20	7,180	0.185	85.5	102.6	513
		0.33	30				111.2	370
		0.87	40				119.7	299
		2.0	50				128.3	257
		4.4	60				136.8	228
		5.0	61				137.7	226
70	2	0.27	50	8,720	0.184	104.4	156.6	313
		0.41	60				167.1	279
		0.55	64				171.2	268
70	3	1.0	30	6,000	0.179	73.8	95.9	320
		5.3	40				103.3	258
		11.0	46				107.7	234
		14.9	50				110.7	221
		21.0	50				110.7	221
70	4	7.5	33	5,200	0.182	62.9	83.6	253
		18.0	38				86.8	228
		95.0	49				93.7	191
		196.0	56				98.1	175
		247.0	56				98.1	175
70	5	65.0	27	4,480	0.180	54.8	69.6	258
		190.0	30				71.2	237
		440.0	35				73.9	211
		1,640.0	40				76.7	192
		3,325.0	45				79.5	177
		6,086.0	47				80.6	172
70	6	2.2	21	4,750	0.177	59.1	71.5	340
		14.0	29				76.2	263
		30.0	32				78.0	244
		84.0	37				80.9	219
		150.0	38				81.6	214
		833.0	50				88.7	177

TABLE 3. TEST NO. 2 - UNIAXIAL STRESS ENDURANCE CREEP BEHAVIOR FOR UTP-19,360B-400/1777 at 70°F

(SHEET 2 OF 2)

T8706

Temperature, F	Sample	Time, min.	Strain, %	Load, g	Area, in.^{2}	Stress (F/A), psi	$\lambda\sigma$, psi	Secant Modulus ($\lambda\sigma/\epsilon$), psi
70	7	0.7	25	5,630	0.183	67.8	84.8	339
		4.0	30				88.1	294
		10.0	35				91.5	261
		26.0	42				96.3	229
		92.0	51				102.4	200
		177.0	57				106.5	187
70	8	10.0	24	4,660	0.184	55.8	69.2	288
		77.0	30				72.5	242
		140.0	32				73.7	230
		1,418.0	44				80.4	182
		2,900.0	49				83.1	169
		3,500.0	49				83.1	169
70	9	10.0	19	4,030	0.178	49.9	59.4	312
		30.0	20				59.9	299
		70.0	22				60.9	277
		140.0	24				61.9	258
		5,496.0	35				67.4	193
		10,040	37				68.4	185
		Unbroken 28,600	≈ 41				70.4	172

3.1.4.1 Constant Rate Modulus

Constant rate modulus tests were run on the 6-in. bar samples described above and on JANNAF Class B specimens. The 6-in. bar samples use the wood-to-wood distance as the effective gage length while the JANNAF's were analyzed using 2.70-in. effective gage length through the test even though it is varying. Strain was determined by the crosshead travel. The constant rate modulus (F(t)) is calculated from the following equation at specific strain levels through the tests.

$$F(t) = \frac{F}{A_o} \frac{\lambda}{\epsilon(t)}$$

where: $\epsilon(t)$ = strain at time t

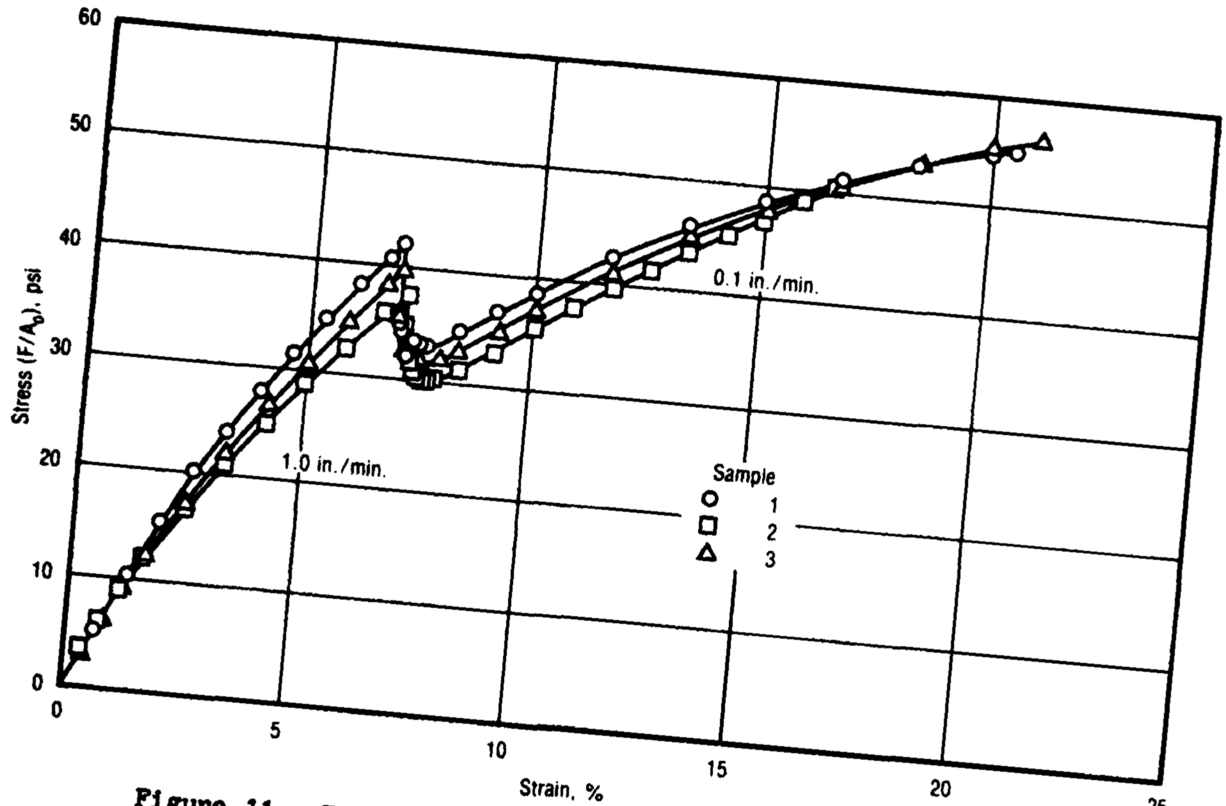

Figure 11. Test No. 3 - High-Low Constant Rate Tests of UTP-19,360B-400/1777 at 70°F

28391

Constant rate modulus data for UTP-3001, with the curve drawn through the small strain portion of the results, are compared to the relaxation modulus in Figure 14. Tabular data for the relaxation and constant rate moduli for 6-in. bars and JANNAF's are given in Table 7.

3.1.5 Multiple Loading Test No. 5

The multiple loading tests on 6-in. bars of UTP-3001 and UTP-19,360B were run five cycles with increasing strain levels for each cycle and with a rest period between cycles. All tests were at 70°F and at crosshead rates of 5, 1, and 0.1 in./min. An attempt was made with UTP-3001 to run at 10 in./min. (i.e., planned rate instead of five) but the data sampling rate did not provide sufficient data points to clearly define the load-time curve, particularly on the first low strain cycle. As previously mentioned, this data had to be reworked.

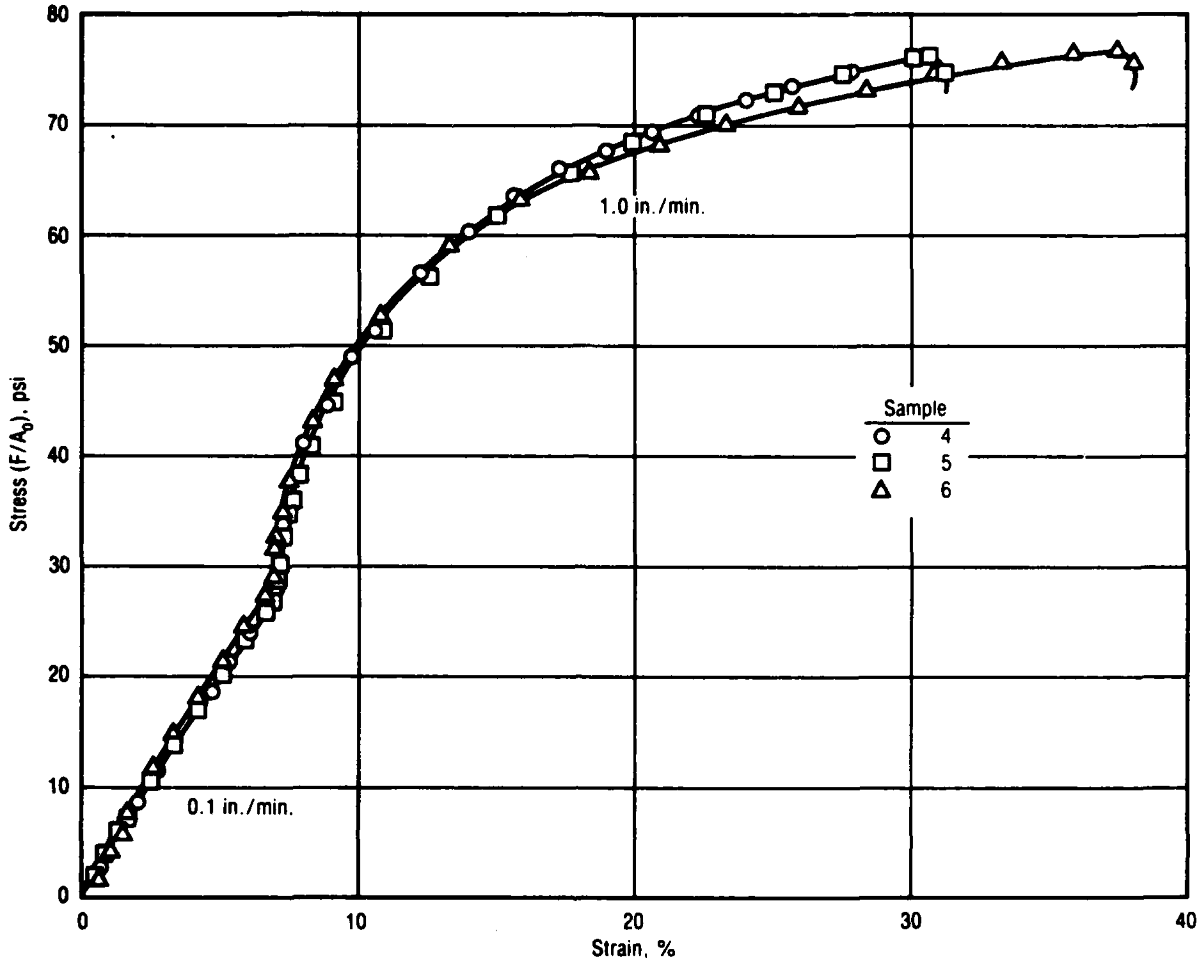

Figure 12. Test No. 3 - Low-High Constant Rate Tests of UTP-19,360B-400/1777 at 70°F

28392

The rework of the data consisted of estimating maximum and minimum stress and strain points that were not picked up by the digitized data acquisition system. The data reduction system computed strain from crosshead travel. This was satisfactory except at and below zero stress. The sample linkage attachment was such that specimens would not be put into compression with the exception of test No. 11, which was run in an Instron with rigid clamp jaws. The actual propellant strain decay was estimated from other tests where strain recovery was monitored by cathetometer measurements for the part of the tests at zero stress (i.e., no load on the samples). The 5-in./min. crosshead test for UTP-19,360B was selected as typical and shown in Figure 15. While the load-unload ramps

TABLE 4. TEST NO. 3 - HIGH-LOW CONSTANT RATE TESTS OF UTP-19,360B-400/1777 AT 70°F WITH 1/2 x 1/2 x 6-IN. BAR SAMPLES

T8707

Sample No. 1	
Crosshead speed, in./min.	1.0 and 0.1
Chart speed, in./min.	10 and 1
Load scale	5 lb/in.
Area, in.	0.500 x 0.501
Gage length, in.	6.00

Chart Distance, in.	Load Signal, in.	Strain, %	Stress (F/A_0), psi
0	0	0	0
0.4	0.26	0.667	5.190
0.8	0.52	1.333	10.379
1.2	0.77	2.00	15.369
1.6	1.00	2.667	19.960
2.0	1.20	3.333	23.952
2.4	1.39	4.00	27.745
2.8	1.57	4.667	31.337
3.2	1.74	5.333	34.731
3.6	1.90	6.00	37.924
4.0	2.04	6.667	40.719
4.15	2.10	6.917	41.916
Change to 0.1 in./min.			
4.20	1.74	7.00	34.731
4.25	1.70	7.083	33.932
4.30	1.68	7.167	33.533
4.40	1.66	7.333	33.134
4.50	1.65	7.50	32.934
4.60	1.65	7.667	32.934
5.0	1.73	8.33	34.531
5.5	1.83	9.167	36.527
6.0	1.93	10.00	38.523
7.0	2.12	11.667	42.315
8.0	2.29	13.333	45.709
9.0	2.43	15.00	48.503
10.0	2.55	16.667	50.898
11.0	2.66	18.33	53.094
12.0	2.74	20.00	54.691
12.3	2.76	70.50	55.090

TABLE 5. TEST NO. 3 - LOW-HIGH CONSTANT RATE TESTS OF UTP-19,360B-400/1777 AT 70°F WITH 1/2 x 1/2 x 6-IN. BAR SAMPLES

T8708

Sample No. 4
Crosshead speed, in./min. 0.1 and 1.0
Chart speed, in./min. 1.0 and 1.0

Load scale 5 lb/in.
Area, in. 0.502 x 0.500
Gage length 6.00

Chart Distance, in.	Load Signal, in.	Strain, %	Stress (F/A_0), psi
0	0	0	0
0.4	0.14	0.667	2.789
0.8	0.28	1.333	5.578
1.2	0.43	2.00	8.566
1.6	0.57	2.667	11.355
2.0	0.69	3.333	13.745
2.4	0.83	4.00	16.534
2.8	0.94	4.667	18.725
3.2	1.07	5.333	21.315
3.6	1.19	6.00	23.705
4.0	1.30	6.667	25.896
4.18	1.36	6.967	27.092
Change to 1 in./min.			
4.2	1.68	7.300	33.466
4.25	2.05	8.134	40.837
4.3	2.23	8.967	44.422
4.35	2.45	9.800	48.805
4.4	2.57	10.634	51.195
4.5	2.82	12.300	56.175
4.6	3.03	13.967	60.359
4.7	3.18	15.634	63.347
4.8	3.30	17.300	65.737
4.9	3.39	18.967	67.530
5.0	3.48	20.634	69.323
5.1	3.55	22.300	70.717
5.2	3.62	23.967	72.112
5.3	3.68	25.634	73.307
5.43	3.75	27.80	74.701

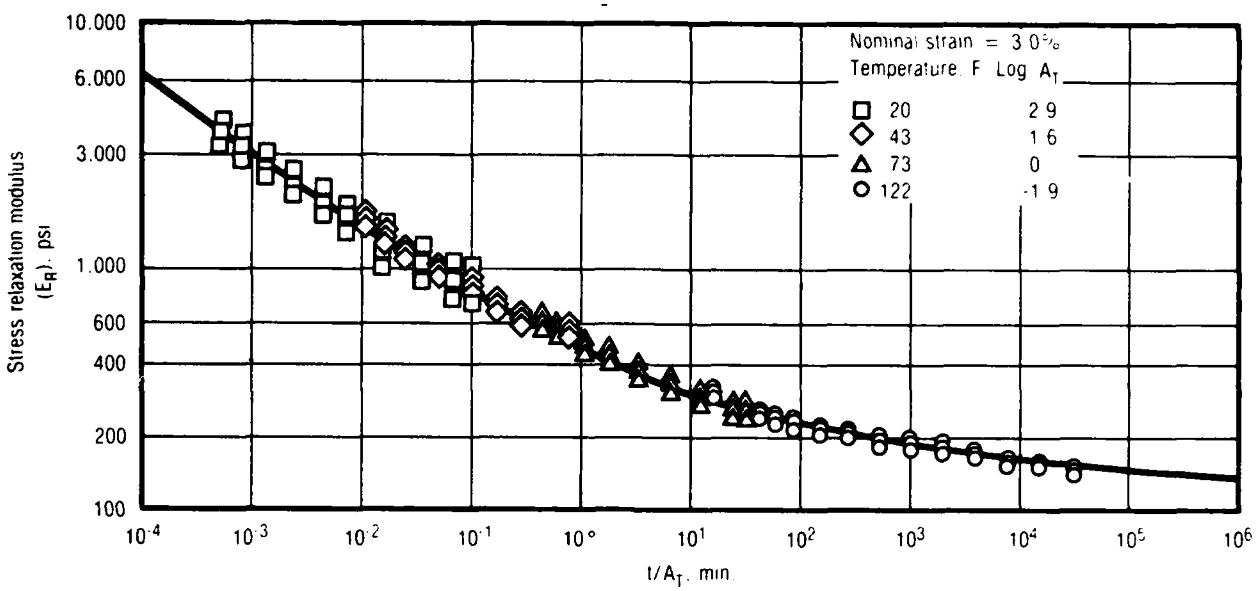

Figure 13. Master Modulus Data for UTP-3001-750/7768 with Experimental Shift

28393

are not clearly shown in the figure because of the scale necessary to show the total test duration, the detailed data are given in Table 8.

3.1.6 Creep Test No. 6

Creep tests were run on 6-in. bars of UTP-3001 and UTP-19,360B by hanging weights on the samples and allowing them to deform under load. The loading was done by setting the weight on the Instron crosshead and then lowering the crosshead away from them as shown in Figure 16. Proper spacing of the segmented weight provided a means of incrementally unloading the samples. The two propellants were run separately to allow access for spacer insertion without disturbing the samples. The procedure for unloading part of the load and still maintaining the balance as a constant load creep test is shown in Figures 17. Tests were run at the maximum load the sample would be sure to survive, then at half and quarter loads. Tests were repeated for 70, 120, and 40° F. The full stress creep test for UTP-19,360B at 71°F is shown as typical. The strain time curve from crosshead and cathetometer measurements is shown in Figure 18 with engineering stress, corrected stress, and secant modulus shown in Figures 19, 20, and 21, respectively. The test data are given in Table 9 and summarized in Table 10 with cathetometer and secant modulus data.

(Text continued on page 29.)

TABLE 6. TEST NO. 4 - 1/2-IN. BAR STRESS RELAXATION DATA REDUCTION

PROPELLANT: UTP 3001 750/7768
REQUESTOR: Carlton
WOR:

DATE: 5/5/81
OPERATOR: JWD

DEFINITIONS:
Time = Time From Start of Test (min)
= Stress (psi)
= Strain (%)
E = Modulus (psi)
T(air) = Test Air Temperature (F)
T(prop) = Test Propellant Temperature (F)

RELATIONSHIPS:
= Force/Area
= Sample Extension/Length
E = (1+)/

NOMINAL TEST CONDITIONS:
Strain = 3 %
Temperature = 73 F
Gage Length = 6.1 in

CALIBRATION DATA:

Pretest: Cal Wt = 5 lbs	SAMPLE 1	2	3
Difflection (lbs/volt)	-0.789	-1.004	-1.016
Zero Offset (volt)	-0.163	-0.120	-0.149

CATHATOMETER STRAIN DATA:

Initial Upper	88105	88265	88205
Initial Lower	73535	73660	73525
Final Upper	88095	88255	88200
Final Lower	73080	73205	73060
Strain (%)	3.05	3.05	3.13

AREAS (sq in)	0.2505	0.2495	0.2495

LOAD DISPLACEMENT DATA: (volt)

TIME			
4.14E-01	-6.12	-4.91	-4.54
6.16E-01	-5.41	-4.34	-4.02
1.02E 00	-4.76	-3.83	-3.55
1.82E 00	-4.21	-3.39	-3.14
3.42E 00	-3.74	-3.01	-2.80
6.62E 00	-3.34	-2.70	-2.51
1.30E 01	-3.01	-2.43	-2.27
2.58E 01	-2.72	-2.21	-2.06
3.03E 01	-2.67	-2.16	-2.02

MODULUS DATA (psi):

TIME	T(prop)	T(air)	SAMPLE 1	2	3	Avg	Std Dev
4.14E-01	70.1	68.2	633.26	652.44	589.05	624.92	22.984
6.16E-01	70.3	68.4	557.20	575.00	519.05	550.42	20.213
1.02E 00	70.1	68.4	488.93	505.35	455.85	483.38	17.828
1.82E 00	70.2	68.0	429.93	445.32	401.31	425.52	15.794
3.42E 00	70.3	68.7	379.74	393.95	355.03	376.24	13.924
6.62E 00	70.2	68.2	337.81	351.28	316.45	335.18	12.421
1.30E 01	70.4	69.3	302.44	315.07	283.73	300.41	11.148
2.58E 01	70.4	69.7	272.03	284.05	255.80	270.63	10.024
3.03E 01	70.6	69.5	265.95	277.74	250.26	264.65	9.746

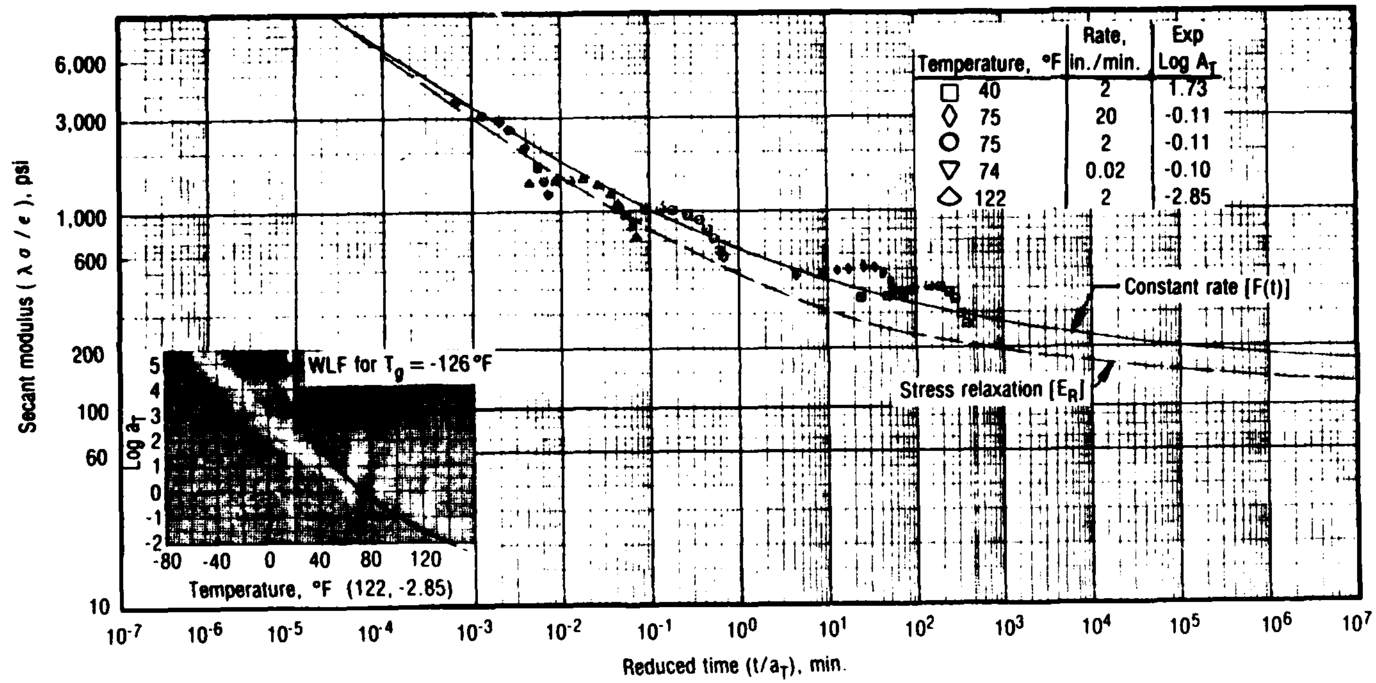

Figure 14. Constant Rate Master Modulus Data for UTP-3001-750/7768 JANNAF Specimens

28394

TABLE 7. MASTER MODULUS CURVES FOR UTP-3001 STRESS RELAXATION AND CONSTANT RATE TESTS

(SHEET 1 OF 2)

T8709

Reduced Time, t/A_T, min.	6-in. Bar, E_R, psi	6-in. Bar, F(t), psi	JANNAF, F(t), psi
1×10^{-5}	-	-	-
2×10^{-5}	-	-	-
4×10^{-5}	8,750*	10,000*	8,750*
6×10^{-5}	7,600*	8,900*	7,800*
8×10^{-5}	6,850*	8,200*	7,150*
1×10^{-4}	6,350*	7,700*	6,700*
2×10^{-4}	5,000*	6,300*	5,400*
4×10^{-4}	4,000*	5,200*	4,450*
6×10^{-4}	3,500	4,650*	3,950*
8×10^{-4}	3,170	4,300	3,630*
1×10^{-3}	3,000	4,070	3,400
2×10^{-3}	2,400	3,350	2,760
4×10^{-3}	1,930	2,760	2,300
6×10^{-3}	1,720	2,520	2,070
8×10^{-3}	1,570	2,320	1,920
1×10^{-2}	1,470	2,180	1,800
2×10^{-2}	1,220	1,830	1,500
4×10^{-2}	1,020	1,550	1,260
6×10^{-2}	910	1,400	1,130
8×10^{-2}	840	1,300	1,070
1×10^{-1}	800	1,240	1,020
2×10^{-1}	675	1,060	870
4×10^{-1}	580	905	765
6×10^{-1}	520	835	705
8×10^{-1}	490	790	665
1×10^{0}	470	755	640
2×10^{0}	412	660	570
4×10^{0}	362	580	510
6×10^{0}	340	540	475
8×10^{0}	320	510	460
1×10^{1}	308	490	440
2×10^{1}	278	445	400
4×10^{1}	256	403	370
6×10^{1}	243	380	352
8×10^{1}	235	365	340

TABLE 7. MASTER MODULUS CURVES FOR UTP-3001 STRESS RELAXATION AND CONSTANT RATE TESTS

(SHEET 2 OF 2)

T8709

Reduced Time, t/A_T, min.	6-in. Bar, E_R, psi	6-in. Bar, F(t), psi	JANNAF, F(t), psi
1×10^2	230	353	332
2×10^2	218	326	310
4×10^2	207	300	290*
6×10^2	201	290	280*
8×10^2	198	280	273*
1×10^3	193	275	268*
2×10^3	185	258*	255*
4×10^3	182	245*	242*
6×10^3	179	236*	235*
8×10^3	172	232*	230*
1×10^4	169	228*	227*
2×10^4	163	219*	218*
4×10^4	157*	210*	210*
6×10^4	154*	205*	205*
8×10^4	152*	203*	202*
1×10^5	151*	200*	200*
2×10^5	147*	193*	194*
4×10^5	143*	188*	188*
6×10^5	141*	184*	185*
8×10^5	140*	182*	183*
1×10^6	139*	181*	182*
2×10^6	136*	177*	178*
4×10^6	133*	174*	174*
6×10^6	131*	171*	172*
8×10^6	130*	169*	170*

* Extrapolated data

3.1.7 Cyclic Loading Test No. 7

Cyclic loading tests were run on 6-in. bars of UTP-3001 and UTP-19,360B propellants at ambient temperature. The cycling was for 20 cycles at nominal strain levels of 4, 8, and 12% for UTP-19,360B with UTP-3001 limited to 12%. At the end of the test (after unloading to zero stress) the strain was monitored on the samples with a cathetometer. The test at a nominal 12% strain is shown in Figure 22 for UTP-19,360B. These data were modified to insert the estimated maximum stress points and the propellant strain decay while at zero stress. Data for the test are given in Table 11. (Text continued on page 34.)

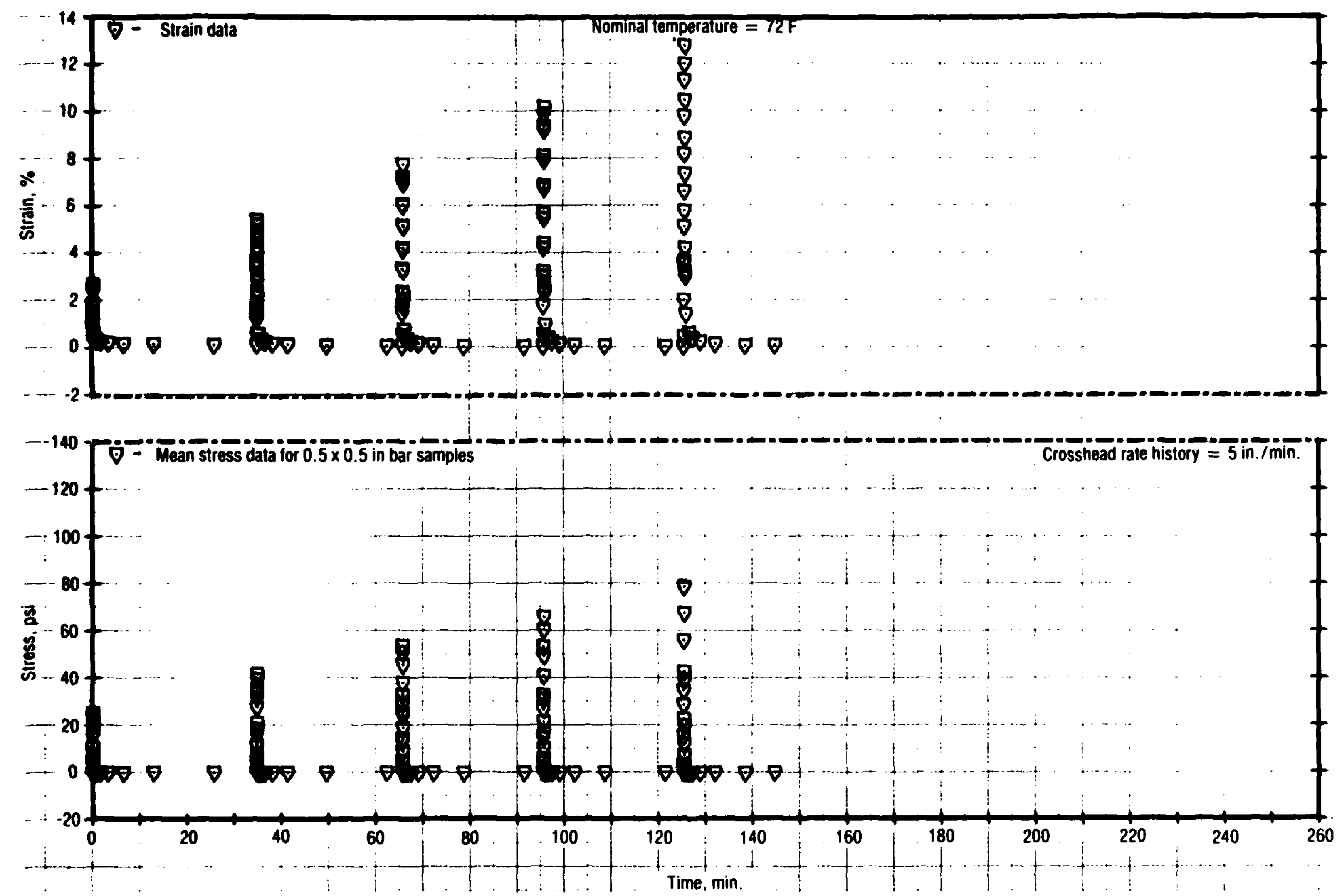

Figure 15. Test No. 5 - Stress While Cycling for UTP-19,360B-400/1777

28746

TABLE 8. TEST NO. 5 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 1 of 3)

PROPELLANT: UTP 19360B 400/1777
REQUESTOR: Carlton
WOR:

DATE: 5/6/81
OPERATOR: JWD

DEFINITIONS:
- Time = Time From Start of Test (min)
- σ = Stress (psi)
- ϵ = Strain (%)
- T(air) = Test Air Temperature (F)
- T(prop) = Test Propellant Temperature (F)

RELATIONSHIPS:
- σ = Force/Area
- ϵ = Sample Extension/Length

NOMINAL VALUES:
- Test Temp = 72 F
- Gage Length = 5.95 in
- Nom. Strain = 2.5,5,7.5,10,12.5 %
- XHD Rate = 5 in/min

CALIBRATION DATA:

Cal Wt = 5.0 lbs

		SAMPLE 1	SAMPLE 2	SAMPLE 3
Load Cal	(lbs/volts)	5.850	6.098	6.118
Offset	(volts)	0.049	0.045	0.093
Pot Cal	(in/volts) =	-0.388		
Temp	(F) =	73.2		

	SAMPLE 1	SAMPLE 2	SAMPLE 3
AREAS (sq in):	0.251	0.253	0.255

STRESS DATA (psi):

SET	Time	T(prop)	T(air)	Strain	SAMPLE 1	SAMPLE 2	SAMPLE 3	Avg.	St Dev
1	0.00607			0.38	3.58	4.13	5.87	4.53	0.847
2	0.01226			0.90	9.89	10.31	11.69	10.63	0.666
3	0.01861			1.42	14.88	15.43	16.64	15.65	0.639
4	0.02409			1.88	18.65	19.37	20.40	19.47	0.622
5	0.03044			2.41	22.58	23.59	24.38	23.52	0.635
6	0.03350			2.68	28.75	24.80	21.40	24.98	2.601
7	0.03595			2.50	25.61	21.61	18.09	21.77	2.660
8	0.04356			1.87	7.62	7.09	6.54	7.08	0.380
9	0.04798			1.51	4.02	3.63	3.21	3.62	0.287
10	0.05238			1.15	1.35	1.04	0.61	1.00	0.264
11	0.05678			0.78	0.00	0.00	0.00	0.00	0.000
12	0.06118			0.74	0.00	0.00	0.00	0.00	0.000
13	0.06558			0.71	0.00	0.00	0.00	0.00	0.000
14	0.27045	73.4	74.2	0.41	0.00	0.00	0.00	0.00	0.000
15	0.47941	73.2	74.4	0.35	0.00	0.00	0.00	0.00	0.000
16	0.87980	73.2	74.4	0.29	0.00	0.00	0.00	0.00	0.000
17	1.68063	73.4	74.2	0.25	0.00	0.00	0.00	0.00	0.000
18	3.28131	73.5	74.1	0.21	0.00	0.00	0.00	0.00	0.000
19	6.48166	73.4	74.0	0.17	0.00	0.00	0.00	0.00	0.000
20	12.88218	73.1	73.8	0.14	0.00	0.00	0.00	0.00	0.000

TABLE 8. TEST NO. 5 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 2 of 3)

21	25.68256	73.2	73.8	0.12	0.00	0.00	0.00	0.00	0.000
22	34.66768	73.0	73.5	0.11	0.00	0.00	0.00	0.00	0.000
23	34.71758			0.11	0.00	0.00	0.00	0.00	0.000
24	34.72338			0.55	3.92	4.37	5.90	4.73	0.733
25	34.73131			1.20	10.75	11.22	12.24	11.40	0.539
26	34.73846			1.80	15.29	15.97	16.78	16.01	0.528
27	34.74564			2.39	19.71	20.74	21.62	20.69	0.674
28	34.75370			3.06	26.25	27.63	28.23	27.37	0.718
29	34.76083			3.66	30.32	31.98	32.35	31.55	0.766
30	34.76802			4.25	33.98	35.94	36.13	35.35	0.841
31	34.77610			4.91	37.81	40.05	40.08	39.32	0.923
32	34.78132			5.40	43.14	44.20	36.90	41.41	2.789
33	34.78324			5.22	37.60	37.80	25.02	33.47	5.177
34	34.79036			4.65	18.67	18.28	17.24	18.06	0.523
35	34.79829			4.00	10.93	10.85	10.29	10.69	0.248
36	34.80544			3.41	6.75	6.68	6.30	6.57	0.172
37	34.81261			2.82	3.54	3.43	3.15	3.37	0.140
38	34.82062			2.16	0.62	0.54	0.22	0.46	0.148
39	34.82773			1.57	0.00	0.00	0.00	0.00	0.000
40	34.83489			1.47	0.00	0.00	0.00	0.00	0.000
41	34.84291			1.32	0.00	0.00	0.00	0.00	0.000
42	34.84542			1.29	0.00	0.00	0.00	0.00	0.000
43	35.05770	72.7	73.6	0.58	0.00	0.00	0.00	0.00	0.000
44	35.65880	72.9	73.5	0.32	0.00	0.00	0.00	0.00	0.000
45	36.45911	72.9	73.7	0.23	0.00	0.00	0.00	0.00	0.000
46	38.05979	73.0	73.6	0.16	0.00	0.00	0.00	0.00	0.000
47	41.26021	73.2	73.4	0.11	0.00	0.00	0.00	0.00	0.000
48	49.53454	72.8	73.7	0.07	0.00	0.00	0.00	0.00	0.000
49	62.33408	73.1	73.6	0.05	0.00	0.00	0.00	0.00	0.000
50	65.57083	73.1	73.7	0.05	0.00	0.00	0.00	0.00	0.000
51	65.63419			0.05	0.00	0.00	0.00	0.00	0.000
52	65.64023			0.51	3.84	4.00	5.67	4.50	0.719
53	65.65171			1.46	12.47	12.96	13.85	13.09	0.495
54	65.66256			2.35	17.93	18.72	19.26	18.64	0.474
55	65.67407			3.32	22.97	24.08	24.41	23.82	0.533
56	65.68479			4.21	27.82	29.43	29.79	29.02	0.742
57	65.69641			5.16	35.79	38.36	38.08	37.68	1.167
58	65.70713			6.06	43.52	46.32	46.19	45.34	1.116
59	65.71874			7.02	48.57	51.74	51.37	50.56	1.227
60	65.72646			7.75	57.69	53.76	48.80	53.42	3.150
61	65.73279			7.20	36.20	36.20	25.20	32.53	4.491
62	65.73567			6.94	25.81	25.63	24.21	25.22	0.617
63	65.74723			6.00	14.15	14.27	13.77	14.06	0.182
64	65.75801			5.10	8.72	8.79	8.53	8.68	0.093
65	65.76963			4.14	4.55	4.58	4.41	4.51	0.066
66	65.78036			3.25	1.38	1.42	1.23	1.34	0.071
67	65.79195			2.29	0.00	0.00	0.00	0.00	0.000
68	65.80268			2.03	0.00	0.00	0.00	0.00	0.000
69	65.81431			1.82	0.00	0.00	0.00	0.00	0.000
70	65.81847			1.75	0.00	0.00	0.00	0.00	0.000
71	66.03134	72.9	73.7	0.73	0.00	0.00	0.00	0.00	0.000

TABLE 8. TEST NO. 5 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 3 of 3)

72	66.63232	73.1	73.9	0.34	0.00	0.00	0.00	0.00	0.000
73	67.43310	73.0	73.9	0.22	0.00	0.00	0.00	0.00	0.000
74	69.03345	73.2	73.9	0.14	0.00	0.00	0.00	0.00	0.000
75	72.23388	73.0	74.1	0.09	0.00	0.00	0.00	0.00	0.000
76	78.63431	73.4	73.6	0.05	0.00	0.00	0.00	0.00	0.000
77	91.43531	73.5	74.2	0.03	0.00	0.00	0.00	0.00	0.000
78	95.45840	73.6	74.4	0.03	0.00	0.00	0.00	0.00	0.000
79	95.51336			0.03	0.00	0.00	0.00	0.00	0.000
80	95.51864			0.50	3.45	3.67	5.45	4.19	0.775
81	95.53371			1.75	13.86	14.40	15.20	14.49	0.478
82	95.54891			3.02	20.31	21.21	21.62	21.05	0.472
83	95.56325			4.21	25.40	26.65	26.88	26.31	0.564
84	95.57846			5.47	31.16	32.90	33.00	32.35	0.732
85	95.59373			6.73	38.82	41.34	41.48	40.55	1.059
86	95.60807			7.92	50.57	54.13	53.90	52.87	1.409
87	95.62321			9.20	57.79	61.50	60.92	60.07	1.412
88	95.63510			10.17	68.50	66.20	62.00	65.57	2.331
89	95.63852			9.89	52.06	49.75	45.21	49.01	2.466
90	95.64465			9.36	31.23	31.23	29.70	30.72	0.624
91	95.65977			8.10	16.46	16.72	16.29	16.49	0.151
92	95.67497			6.84	7.82	10.10	9.85	9.92	0.111
93	95.68931			5.65	5.59	5.75	5.60	5.65	0.062
94	95.70458			4.39	1.94	2.02	1.89	1.95	0.049
95	95.71904			3.19	0.00	0.00	0.00	0.00	0.000
96	95.73412			2.75	0.00	0.00	0.00	0.00	0.000
97	95.74936			2.42	0.00	0.00	0.00	0.00	0.000
98	95.75644			2.30	0.00	0.00	0.00	0.00	0.000
99	95.96929	73.4	74.5	0.94	0.00	0.00	0.00	0.00	0.000
100	96.57051	73.6	74.2	0.39	0.00	0.00	0.00	0.00	0.000
101	97.37122	73.4	74.5	0.23	0.00	0.00	0.00	0.00	0.000
102	98.97161	73.6	74.3	0.13	0.00	0.00	0.00	0.00	0.000
103	102.17252	73.9	74.5	0.07	0.00	0.00	0.00	0.00	0.000
104	108.57293	73.7	74.8	0.04	0.00	0.00	0.00	0.00	0.000
105	121.37377	73.6	74.8	0.02	0.00	0.00	0.00	0.00	0.000
106	125.26766	73.9	75.0	0.02	0.00	0.00	0.00	0.00	0.000
107	125.30455			0.02	0.00	0.00	0.00	0.00	0.000
108	125.31476			0.44	2.23	2.61	4.58	3.14	0.893
109	125.33331			1.98	14.64	15.21	15.93	15.26	0.456
110	125.35209			3.54	21.65	22.61	22.92	22.39	0.469
111	125.37104			5.10	27.41	28.82	28.92	28.38	0.597
112	125.38915			6.60	33.21	35.02	34.98	34.41	0.730
113	125.40790			8.18	40.69	43.17	43.09	42.32	0.996
114	125.42679			9.79	53.02	56.85	56.84	55.57	1.562
115	125.44500			11.32	64.68	68.70	68.06	67.15	1.530
116	125.46186			12.78	75.91	80.14	78.85	78.30	1.533
117	125.47103			12.00	39.33	39.46	37.49	38.76	0.780
118	125.48971			10.46	19.18	19.64	19.18	19.33	0.186
119	125.50862			8.85	11.55	11.88	11.69	11.71	0.115
120	125.52677			7.34	6.79	7.04	6.91	6.91	0.089
121	125.54563			5.77	2.91	3.08	2.96	2.98	0.062
122	125.56456			4.19	0.00	0.00	0.00	0.00	0.000
123	125.58264			3.64	0.00	0.00	0.00	0.00	0.000
124	125.60146			3.21	0.00	0.00	0.00	0.00	0.000
125	125.61392			2.98	0.00	0.00	0.00	0.00	0.000
126	125.82705	73.8	74.7	1.39	0.00	0.00	0.00	0.00	0.000
127	126.42856	74.0	74.9	0.60	0.00	0.00	0.00	0.00	0.000
128	127.22920	73.7	74.9	0.36	0.00	0.00	0.00	0.00	0.000
129	128.82993	74.0	75.4	0.21	0.00	0.00	0.00	0.00	0.000
130	132.03025	74.0	75.1	0.12	0.00	0.00	0.00	0.00	0.000
131	138.43101	74.1	75.4	0.06	0.00	0.00	0.00	0.00	0.000
132	144.67834	74.3	75.7	0.05	0.00	0.00	0.00	0.00	0.000

13045-1

Figure 16. Test No. 6 - Creep Test with 6-in. Bar Specimens

28747

3.1.8 Relaxation Test No. 8

Stress relaxation tests were run on 6-in. bars of UTP-3001 and UTP-19,360B propellant for a 24-hr period and then monitored for strain decay after they were unloaded. The tests at ambient temperature were repeated for 4, 8, and 12% nominal strain levels for UTP-19,360B but limited to 4% for UTP-3001. They were loaded at a crosshead rate of 20 in./min. and unloaded at 1 in./min. after the 24-hr relaxation. A plot for the UTP-19,360B at 4% nominal strain is shown as typical in Figure 23, and data are given in Table 12.

3.1.9 Predamaged-Relaxation Test No. 9

The predamage-relaxation tests were run with 6-in. bars on UTP-19,360B propellant at ambient temperature. They were preloaded to 12% and unloaded at a crosshead rate of 0.1 in./min., allowed to rest, then reloaded to 8 or 4% strain at 20 in./min. After relaxing 1 hr the samples were unloaded at 1.0 in./min. and strain was monitored after unloading. These tests were repeated for a 6% predamage strain followed by a reload to 4 or 2% as above. The 12% predamage followed by 8% stress relaxation for UTP-19,360B is shown in Figure 24, and tabular data are given in Table 13. Comparison data for UTP-3001 was limited to 6% predamage followed by 3% relaxation. These data were modified to obtain the peak stress and strain relaxation after the samples were unloaded. Strain was monitored with a cathetometer after the relaxation part of the test.

3.1.10 Complex Multiple Load Test No. 10

The complex multiple load tests were run with 6-in. bars on UTP-3001 and UTP-19,360B propellants. Tests were run at crosshead rates of 5, 1, and

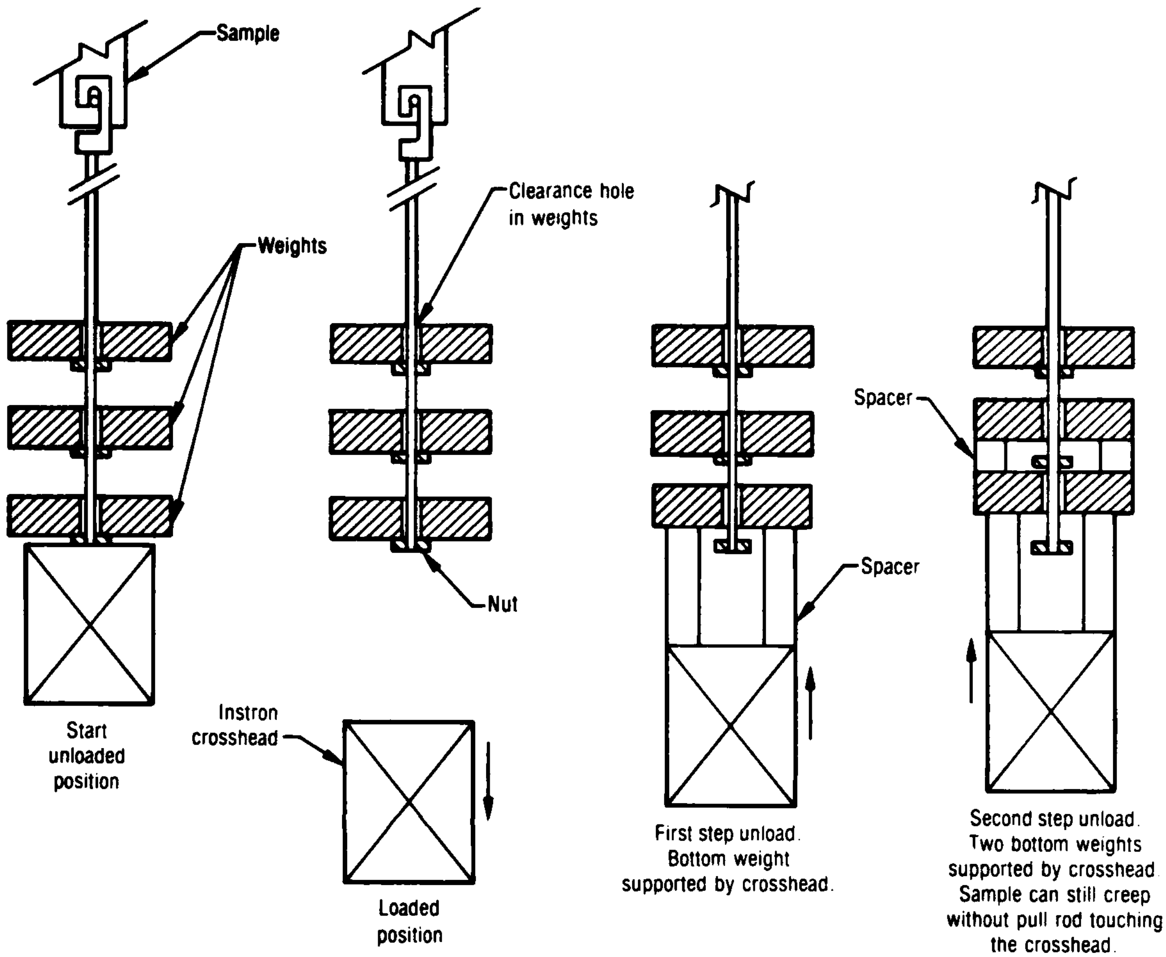

Figure 17. Procedure for Loading and Incrementally Unloading Creep Samples
28805

0.1 in./min. The test sequence was 12 to 8 to 12 to 4% strain, then unload, reload to 4% strain, and unload (four cycles) with cathetometer monitoring of strain decay. The same type of sequence was repeated with maximum strains of 8 and then 4% where the 4% maximum strain was shortened by one cycle. The 5 in./min., 12% maximum strain test on UTP-19,360B as typical is shown in Figure 25, and tabular data are given in Table 14. The data were reworked to insert maximum and minimum stress values as well as strain decay for unloaded specimens. The cathetometer strain after the final unload was incorporated into the data. The 5 in./min 12% strain test for UTP-3001 was deleted because the modulus was outside the range of the remainder of the data (i.e. carton to carton difference).

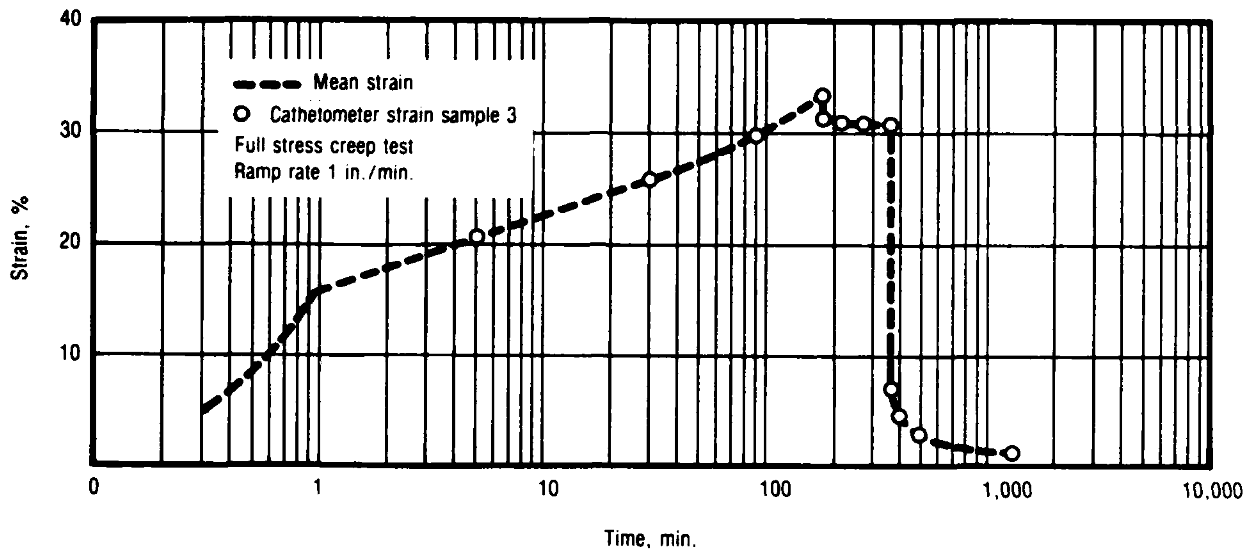

Figure 18. Test No. 6 - Strain-Time Data for Creep Test of UTP-19,360B-400/1777 at 71°F

28748

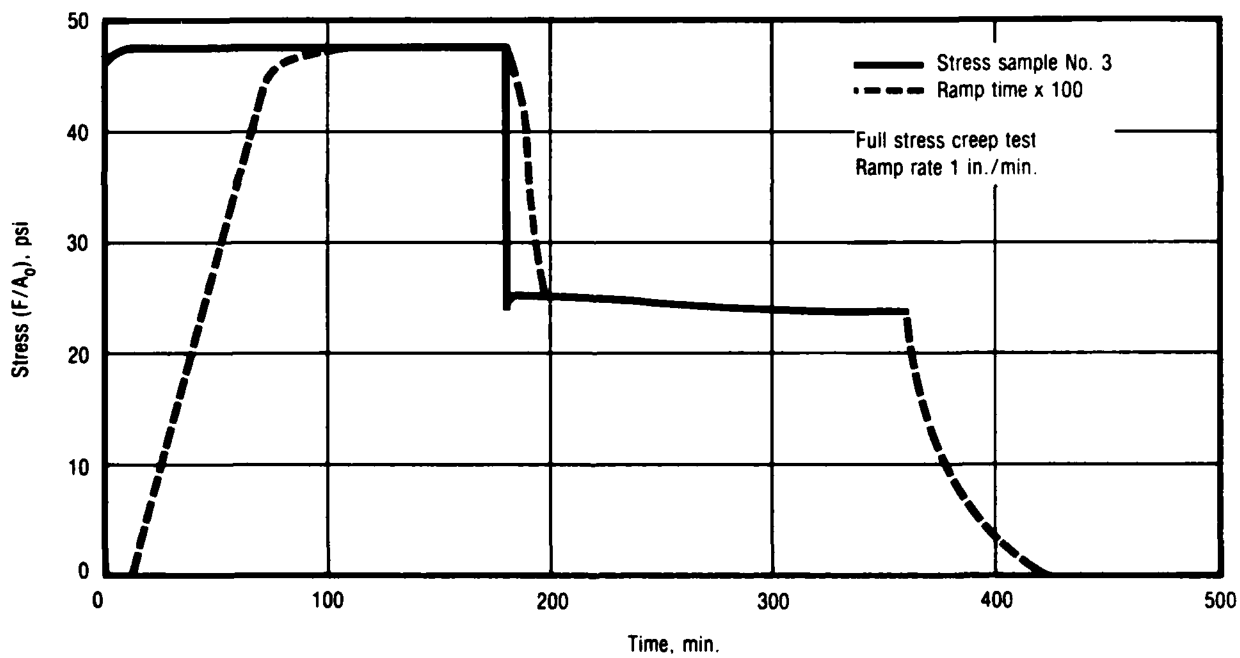

Figure 19. Stress-Time Data for Creep Test of UTP-19,360B-400/1777 at 71°F.

28749

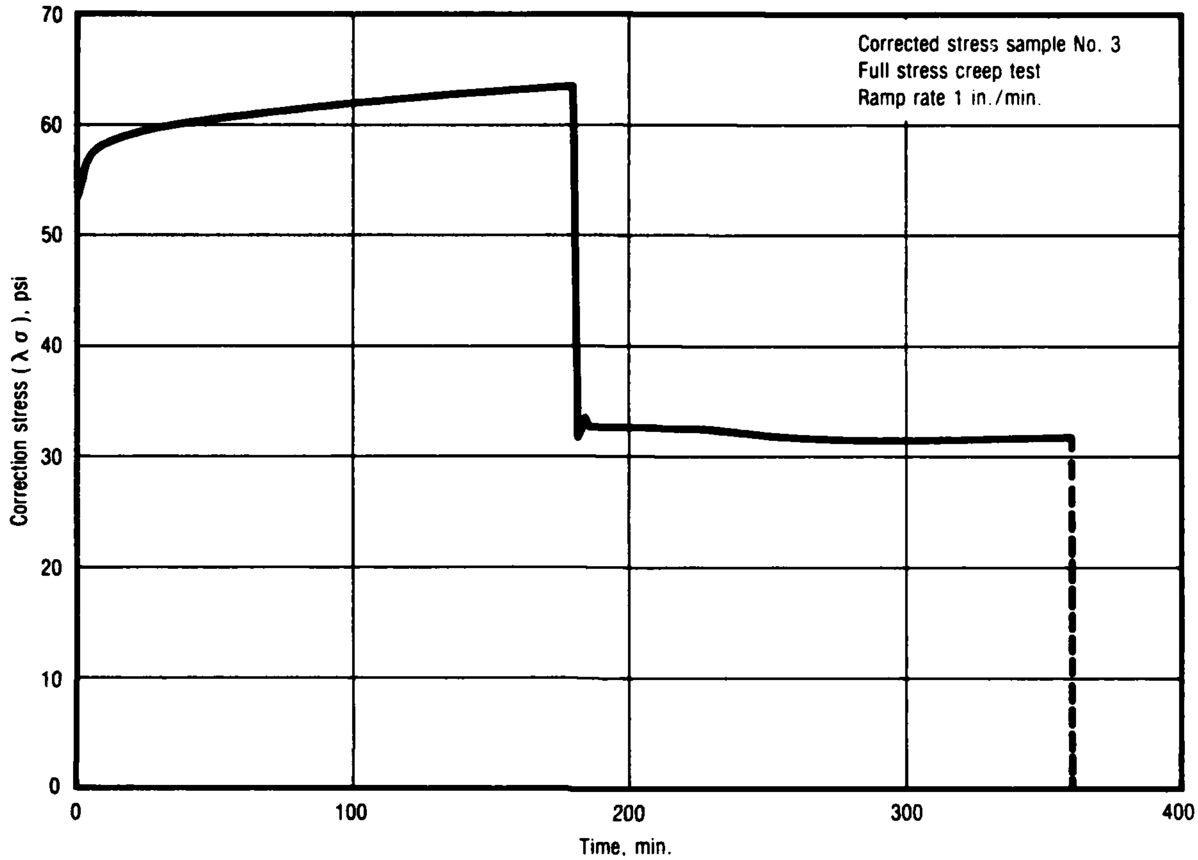

Figure 20. Corrected Stress-Time Data for Creep Test of UTP-19,360B-400/1777 at 71 °F

28750

3.1.11 Quinlan Complex History Test No. 11A

This particular test is very complex and required 2 full months to complete. It was run with single samples (one at a time) in an Instron using 6-in. bar specimens of UTP-3001 and UTP-19,360B propellant. The samples were pinned through the redwood end tabs and clamped onto pins to avoid crushing the redwood (because that would generate a compression load on the sample) during attachment. All coupling joints were heavy and tightly pinned so that the sample would be put into compression when returned to the zero strain position.

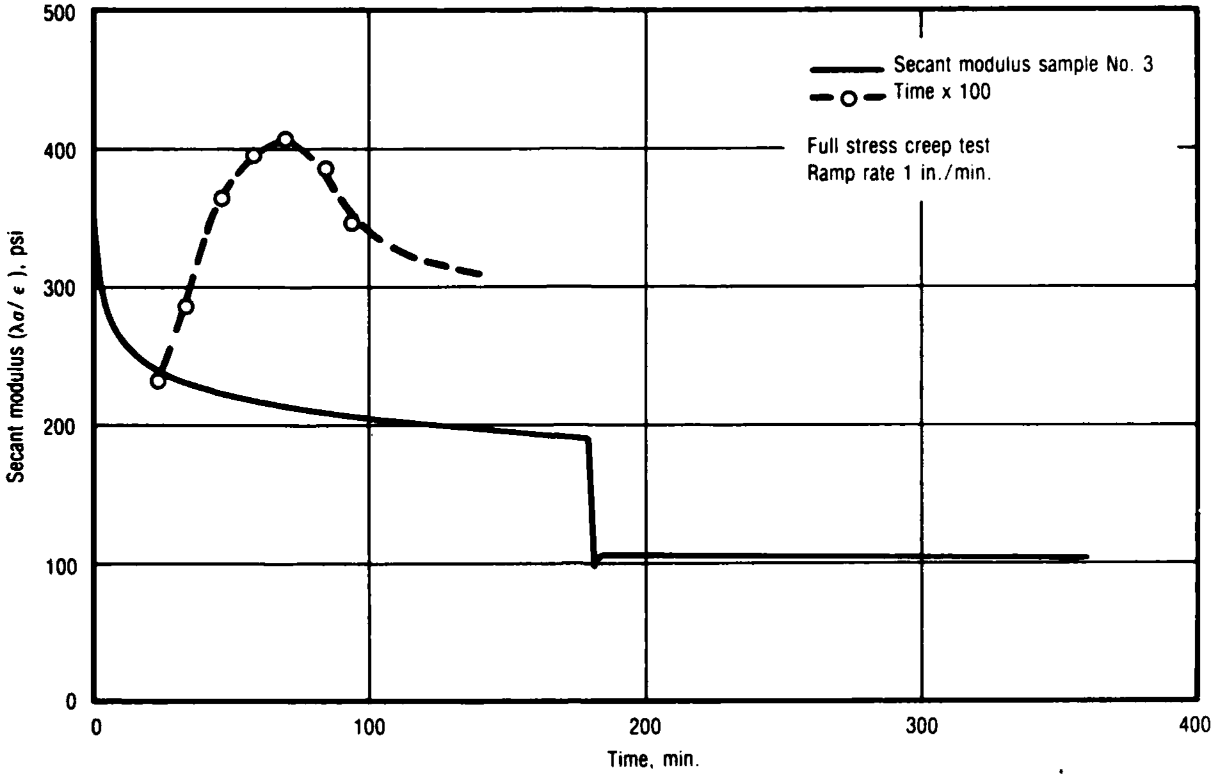

Figure 21. Secant Modulus Data for Creep Test of UTP-19,360B-400/1777 at 71°F

28752

The test on UTP-3001 is presented but the test is so complex that it has been divided into three parts. Part 1 is described in Table 15 with data given in Table 16. Since an actual Instron trace of the load-time curve was obtained, the peaks and minimum (compression) stresses were selected data reduction points. Part 1 of the test is expanded in time scale to show some detail of the process (Figures 26 through 29). Part 2 is described in Table 17 with data given in Table 18. Test sequence for Part 2 is shown in Figures 30, 31, and 32. Part 3 (selected cycle maximum and minimum) are given in Table 19. The last figure of this part (Figure 32) is some of the cyclic loading at the end of the test. The chart speed was set such that good definition of the cycles could be recorded.

(Text continued on page 64.)

TABLE 9. TEST NO. 6 - 1/2-IN. BAR STRESS WHILE CYCLING (FULL STRESS CREEP) (SHEET 1 OF 8)

PROPELLANT: UTP 19360B 400/1777
REQUESTOR: Carlton
WOR:

DATE: 5/7/81
OPERATOR: JWD

DEFINITIONS:
Time = Time From Start of Test (min)
= Stress (psi)
= Strain (%)
T(air) = Test Air Temperature (F)
T(prop) = Test Propellant Temperature (F)

RELATIONSHIPS:
= Force/Area
= Sample Extension/Length

NOMINAL VALUES:
Test Temp = 71 F
Gage Length = 6.00 in
Nom. Strain = 3 %
XHD Rate = 1 in/min

CALIBRATION DATA:

		SAMPLE 1	SAMPLE 2	SAMPLE 3
Cal Wt = 5.0 lbs				
Load Cal	(lbs/volts)	5.85	6.09	6.12
Offset	(volts)	0.03	0.03	0.07
Pot Cal	(in/volts) =	-0.38		
Temp	(F) =	72.5		

AREAS (sq in): 0.252 0.250 0.251

STRESS DATA (psi):

Time	T(prop)	T(air)	Strain	SAMPLE 1	SAMPLE 2	SAMPLE 3	Avg	St Dev
6.5768E-03			0.11	0.00	-0.02	0.01	-0.00	0.010
1.3369E-02			0.22	0.00	-0.00	-0.00	-0.00	0.001
2.0152E-02			0.34	0.00	0.00	-0.01	-0.00	0.004
2.6935E-02			0.45	-0.02	-0.00	-0.01	-0.01	0.005
3.3710E-02			0.56	0.01	-0.01	0.00	0.00	0.006
4.0485E-02			0.68	0.00	0.00	0.01	0.00	0.003
4.7252E-02			0.79	-0.00	0.00	0.01	0.00	0.003
5.4019E-02			0.90	-0.00	-0.00	-0.01	-0.00	0.001
6.0802E-02			1.01	-0.02	0.01	-0.01	-0.01	0.009
6.7569E-02			1.13	0.01	-0.00	-0.00	0.00	0.006
7.4344E-02			1.25	0.01	0.04	0.00	0.02	0.016
8.1110E-02			1.37	-0.02	0.12	-0.00	0.03	0.052
8.7885E-02			1.46	-0.00	0.24	-0.01	0.07	0.099
9.4677E-02			1.59	-0.02	0.69	-0.01	0.22	0.285
1.0147E-01			1.70	0.00	1.33	-0.00	0.44	0.542
1.0827E-01			1.81	-0.01	1.81	0.01	0.60	0.738
1.1504E-01			1.90	0.00	2.25	-0.00	0.75	0.920
1.2184E-01			2.01	-0.01	2.80	-0.01	0.93	1.146
1.2862E-01			2.13	-0.02	3.24	0.00	1.07	1.324
1.3542E-01			2.23	0.00	4.10	0.02	1.37	1.669
1.4220E-01			2.36	-0.03	4.92	0.04	1.64	2.006
1.4900E-01			2.45	-0.00	5.31	0.06	1.79	2.156
1.5580E-01			2.56	-0.02	5.95	0.84	2.26	2.282

TABLE 9. TEST NO. 6 - 1/2-IN. BAR STRESS WHILE CYCLING (FULL STRESS CREEP)
(SHEET 2 OF 8)

1.6259E-01	2.68	0.23	6.78	1.79	2.93	2.418
1.6939E-01	2.79	0.72	7.42	2.78	3.64	2.425
1.7620E-01	2.86	1.27	7.77	3.65	4.23	2.327
1.8303E-01	2.95	2.07	8.33	4.41	4.94	2.236
1.8985E-01	3.13	2.62	8.77	5.09	5.49	2.188
1.9668E-01	3.08	3.09	9.05	5.72	5.95	2.111
2.0352E-01	3.44	3.66	9.52	6.34	6.51	2.075
2.1037E-01	3.27	4.25	10.10	7.10	7.15	2.070
2.1722E-01	3.35	4.85	10.60	7.75	7.73	2.033
2.2405E-01	3.31	5.45	11.05	8.39	8.30	1.979
2.3089E-01	2.97	5.91	11.31	8.72	8.65	1.911
2.3773E-01	3.70	6.21	11.41	8.95	8.86	1.839
2.4457E-01	3.63	6.47	11.56	9.16	9.07	1.800
2.5141E-01	3.22	6.86	11.97	9.67	9.50	1.809
2.5826E-01	3.86	7.12	12.11	9.87	9.70	1.765
2.6509E-01	3.85	7.46	12.35	10.19	10.00	1.730
2.7194E-01	3.92	7.89	12.78	10.70	10.46	1.733
2.7880E-01	3.31	8.30	13.11	11.16	10.86	1.712
2.8568E-01	3.36	8.89	13.56	11.62	11.36	1.660
2.9255E-01	4.09	9.17	13.78	12.03	11.66	1.645
2.9943E-01	4.05	9.38	13.98	12.30	11.89	1.644
3.0631E-01	4.15	10.09	14.57	12.86	12.50	1.600
3.1319E-01	4.38	10.75	15.15	13.57	13.16	1.575
3.2004E-01	4.43	11.24	15.63	14.04	13.64	1.572
3.2691E-01	4.58	11.85	16.13	14.61	14.20	1.534
3.3378E-01	5.52	12.46	16.66	15.18	14.77	1.503
3.4064E-01	4.39	12.78	16.94	15.52	15.08	1.496
3.4753E-01	3.14	13.18	17.26	15.71	15.39	1.458
3.5442E-01	4.64	13.60	17.66	16.16	15.81	1.453
3.6129E-01	4.61	13.88	17.85	16.62	16.12	1.438
3.6814E-01	5.00	14.90	18.81	17.69	17.13	1.425
3.7500E-01	5.10	15.54	19.51	18.61	17.89	1.474
3.8187E-01	4.82	16.14	20.02	19.10	18.42	1.434
3.8874E-01	4.83	16.67	20.61	19.77	19.02	1.468
3.9561E-01	5.61	17.24	21.19	20.41	19.61	1.480
4.0249E-01	5.57	17.74	21.75	21.02	20.17	1.510
4.0936E-01	5.90	18.35	22.28	21.67	20.77	1.496
4.1623E-01	6.15	18.90	22.78	22.31	21.33	1.495
4.2311E-01	2.32	19.41	23.29	22.88	21.86	1.507
4.2995E-01	6.19	19.90	23.79	23.47	22.39	1.527
4.3680E-01	6.34	20.42	24.21	24.05	22.89	1.514
4.4367E-01	6.40	20.96	24.75	24.64	23.45	1.526
4.5056E-01	6.17	21.42	25.30	25.20	23.97	1.563
4.5743E-01	6.69	21.96	25.68	25.76	24.46	1.536
4.6429E-01	6.47	22.43	26.24	26.32	25.00	1.571
4.7116E-01	6.85	22.94	26.68	26.87	25.50	1.568
4.7804E-01	6.78	23.44	27.11	27.45	26.00	1.571
4.8491E-01	6.83	23.91	27.66	27.97	26.51	1.600
4.9177E-01	7.10	24.38	28.00	28.48	26.96	1.585
4.9862E-01	7.31	24.85	28.50	29.05	27.46	1.615
5.0548E-01	8.44	25.33	29.05	29.56	27.98	1.632
5.1234E-01	7.50	25.81	29.52	30.07	28.46	1.638
5.1919E-01	5.41	26.26	29.89	30.56	28.90	1.636
5.2604E-01	6.48	26.71	30.38	30.99	29.36	1.635

TABLE 9. TEST NO. 6 - 1/2-IN. BAR STRESS WHILE CYCLING (FULL STRESS CREEP)
(SHEET 3 OF 8)

5.3290E-01	8.05	27.19	30.77	31.48	29.82	1.625
5.3979E-01	7.97	27.66	31.22	32.08	30.32	1.655
5.4665E-01	8.04	28.09	31.67	31.59	30.45	1.445
5.5351E-01	8.21	28.57	32.06	32.66	31.10	1.565
5.6038E-01	8.23	28.99	32.58	33.27	31.61	1.623
5.6724E-01	8.23	29.43	33.08	33.78	32.10	1.653
5.7411E-01	8.44	29.90	33.40	34.37	32.56	1.661
5.8099E-01	8.73	30.33	33.87	34.84	33.02	1.679
5.8786E-01	8.73	30.78	34.22	35.34	33.45	1.680
5.9474E-01	8.86	31.19	34.62	35.85	33.88	1.707
6.0159E-01	8.79	31.64	35.09	36.32	34.35	1.716
6.0845E-01	9.09	32.07	35.45	36.79	34.77	1.720
6.1534E-01	1.29	32.51	35.93	37.32	35.26	1.751
6.2222E-01	10.45	32.91	36.34	37.72	35.66	1.751
6.2909E-01	7.98	33.36	36.67	38.21	36.08	1.754
6.3597E-01	9.54	33.77	37.09	38.68	36.51	1.773
6.4284E-01	9.80	34.20	37.50	39.15	36.95	1.782
6.4972E-01	9.21	34.62	37.89	39.64	37.38	1.800
6.5659E-01	10.54	35.01	38.32	40.05	37.79	1.809
6.6347E-01	10.37	35.42	38.65	40.46	38.18	1.805
6.7037E-01	10.12	35.87	39.11	40.99	38.66	1.833
6.7724E-01	9.86	36.24	39.49	41.36	39.03	1.831
6.8411E-01	10.70	36.63	39.80	41.81	39.42	1.848
6.9099E-01	12.76	37.05	40.19	42.26	39.83	1.857
6.9787E-01	9.06	37.42	40.52	42.61	40.18	1.847
7.0474E-01	11.11	37.83	40.89	43.14	40.62	1.884
7.1159E-01	10.55	38.22	41.30	43.54	41.02	1.887
7.1843E-01	10.23	38.60	41.64	43.78	41.34	1.841
7.2529E-01	12.77	38.98	41.98	44.26	41.74	1.872
7.3214E-01	9.72	39.33	42.36	44.69	42.13	1.901
7.3900E-01	9.36	39.71	42.67	44.88	42.42	1.834
7.4587E-01	4.69	40.10	43.00	45.36	42.82	1.865
7.5274E-01	11.98	40.38	42.93	45.39	42.90	1.770
7.5961E-01	11.21	40.75	43.08	45.44	43.09	1.658
7.6650E-01	11.96	41.10	43.33	46.08	43.50	1.764
7.7339E-01	37.69	41.48	43.73	46.15	43.79	1.650
7.8026E-01	43.11	41.84	44.14	45.97	43.99	1.461
7.8713E-01	35.99	42.23	44.52	46.32	44.36	1.450
7.9399E-01	1.93	42.54	44.92	46.30	44.58	1.345
8.0088E-01	26.04	42.94	45.19	46.07	44.73	1.143
8.0774E-01	44.21	43.21	45.52	46.49	45.07	1.192
8.1458E-01	30.89	43.53	45.80	46.30	45.21	1.046
8.2142E-01	34.35	43.95	45.91	46.03	45.30	0.827
8.2829E-01	16.06	44.16	46.26	46.41	45.61	0.888
8.3516E-01	23.10	44.54	46.61	45.95	45.70	0.746
8.4203E-01	16.13	44.89	46.85	45.89	45.87	0.693
8.4890E-01	37.71	45.18	47.25	46.10	46.18	0.734
8.5579E-01	50.98	45.49	47.03	45.78	46.10	0.581
8.6268E-01	2.00	45.84	46.56	46.53	46.31	0.288
8.6954E-01	32.40	46.14	47.26	46.53	46.65	0.401
8.7643E-01	40.79	46.49	47.57	46.46	46.84	0.448
8.8333E-01	55.74	46.74	47.66	46.87	47.09	0.353
8.9024E-01	45.38	47.02	47.83	46.59	47.15	0.446
8.9711E-01	42.09	47.31	47.43	46.85	47.19	0.216

TABLE 9. TEST NO. 6 - 1/2-IN. BAR STRESS WHILE CYCLING (FULL STRESS CREEP) (SHEET 4 OF 8)

9.0399E-01			22.01	47.58	47.74	46.70	47.34	0.395
9.1087E-01			28.99	47.95	47.86	46.74	47.52	0.476
9.1776E-01			20.34	48.15	47.51	46.98	47.54	0.414
9.2467E-01			28.52	48.37	47.95	46.72	47.68	0.608
9.3155E-01			17.49	48.71	47.64	47.05	47.80	0.597
9.3843E-01			19.77	48.93	47.80	46.66	47.80	0.802
9.4532E-01			22.90	49.24	47.88	46.71	47.94	0.896
9.5221E-01			47.14	49.46	47.79	46.65	47.96	0.999
9.5910E-01			34.88	49.68	48.08	46.43	48.06	1.149
9.6599E-01			16.59	49.95	47.81	46.84	48.20	1.125
9.7286E-01			14.04	50.25	47.90	46.83	48.33	1.239
9.7973E-01			41.21	50.64	47.91	46.83	48.46	1.388
9.8663E-01			24.22	50.63	47.66	46.77	48.35	1.427
9.9354E-01			15.17	50.78	47.97	46.60	48.45	1.507
1.0004E 00			16.18	51.13	47.87	46.89	48.63	1.569
1.0073E 00			15.71	50.98	47.89	47.04	48.63	1.465
1.0142E 00			15.22	50.99	48.06	47.04	48.70	1.449
1.0210E 00			16.31	51.28	47.82	47.23	48.78	1.545
1.0279E 00			16.40	51.04	48.03	46.93	48.67	1.506
1.0348E 00			16.35	51.25	47.95	47.13	48.78	1.544
1.0417E 00			16.03	51.26	47.94	47.23	48.81	1.520
1.0486E 00			16.18	51.34	48.14	47.07	48.85	1.570
1.0554E 00			16.45	51.32	47.91	47.36	48.86	1.518
1.0623E 00			16.53	51.32	48.02	47.05	48.80	1.585
1.0692E 00			16.55	51.13	47.93	46.99	48.68	1.534
1.0760E 00			16.66	51.32	47.72	47.00	48.68	1.634
1.0829E 00			16.77	51.45	48.02	46.65	48.70	1.748
1.0898E 00			16.86	51.21	47.86	46.87	48.65	1.606
1.0967E 00			17.00	51.31	47.82	46.76	48.63	1.684
1.1036E 00			17.10	51.29	48.05	46.72	48.68	1.662
1.1105E 00			17.22	51.45	47.80	47.04	48.76	1.666
1.1174E 00			17.32	51.49	48.07	46.88	48.82	1.694
1.1243E 00			17.43	51.30	47.85	47.15	48.77	1.569
1.1313E 00			17.54	51.13	48.02	46.79	48.64	1.582
5.9537E 00	72.0	73.1	38.12	0.01	-0.04	47.39	15.78	19.353
6.1544E 00	72.2	72.9	38.12	0.01	-0.04	47.40	15.79	19.355
6.5547E 00	72.2	72.9	38.12	0.01	-0.04	47.22	15.73	19.284
7.3555E 00	72.2	72.5	38.12	0.01	-0.04	47.38	15.78	19.350
8.9560E 00	72.4	72.5	38.12	[illegible]	-0.03	47.52	15.83	19.410
1.2157E 01	72.3	72.3	38.11	-0.42	-0.44	47.41	15.52	19.529
1.8557E 01	72.1	72.7	38.12	-0.41	-0.52	47.53	15.53	19.595
3.1357E 01	72.4	72.6	38.09	-0.40	-0.54	47.49	15.52	19.581
5.6958E 01	72.1	73.5	43.70	-0.39	-0.54	47.32	15.46	19.508
1.0816E 02	72.9	73.7	49.44	-0.38	-0.57	47.46	15.50	19.571
1.8125E 02	74.5	75.9	46.48	-0.36	-0.52	47.71	15.61	19.657
1.8138E 02			46.35	-0.37	-0.52	47.62	15.57	19.621
1.8139E 02			46.20	-0.36	-0.51	47.66	15.60	19.635
1.8140E 02			46.06	-0.35	-0.51	47.63	15.59	19.621
1.8141E 02			45.93	-0.38	-0.51	47.75	15.62	19.675
1.8142E 02			45.78	-0.36	-0.52	47.72	15.61	19.660
1.8143E 02			45.63	-0.38	-0.52	47.76	15.62	19.679
1.8143E 02			45.50	-0.36	-0.53	47.61	15.57	19.620
1.8144E 02			45.36	-0.36	-0.52	47.60	15.57	19.613
1.8145E 02			45.21	-0.38	-0.52	47.58	15.56	19.610

Failure

TABLE 9. TEST NO. 6 - 1/2-IN. BAR STRESS WHILE CYCLING (FULL STRESS CREEP)
(SHEET 5 OF 8)

1.8146E 02	45.05	-0.36	-0.52	47.57	15.56	19.601
1.8147E 02	44.92	-0.37	-0.51	47.76	15.63	19.676
1.8148E 02	44.77	-0.36	-0.51	47.71	15.62	19.655
1.8149E 02	44.62	-0.35	-0.51	46.97	15.37	19.352
1.8149E 02	44.50	-0.35	-0.52	46.47	15.20	19.147
1.8150E 02	44.37	-0.35	-0.52	46.53	15.22	19.172
1.8151E 02	44.21	-0.35	-0.51	46.22	15.12	19.043
1.8152E 02	44.08	-0.35	-0.51	45.42	14.85	18.719
1.8153E 02	43.93	-0.36	-0.52	44.85	14.66	18.491
1.8154E 02	43.79	-0.35	-0.52	44.33	14.49	18.277
1.8155E 02	43.64	-0.35	-0.51	44.04	14.39	18.154
1.8156E 02	43.51	-0.36	-0.52	42.93	14.02	17.703
1.8156E 02	43.35	-0.36	-0.52	41.13	13.42	16.968
1.8157E 02	43.22	-0.36	-0.51	39.97	13.03	16.493
1.8158E 02	43.07	-0.36	-0.51	39.97	13.03	16.497
1.8159E 02	42.92	-0.36	-0.51	37.16	12.10	15.348
1.8160E 02	42.79	-0.39	-0.52	35.20	11.43	14.554
1.8161E 02	42.65	-0.36	-0.52	34.22	11.12	14.150
1.8162E 02	42.52	-0.36	-0.51	32.24	10.45	13.339
1.8162E 02	42.36	-0.37	-0.53	30.53	9.88	12.649
1.8163E 02	42.22	-0.35	-0.51	28.86	9.33	11.961
1.8164E 02	42.10	-0.36	-0.52	27.38	8.84	11.359
1.8165E 02	41.92	-0.37	-0.52	26.13	8.41	10.849
1.8166E 02	41.81	-0.36	-0.51	25.11	8.08	10.429
1.8167E 02	41.68	-0.37	-0.51	24.16	7.76	10.042
1.8168E 02	41.48	-0.37	-0.51	23.41	7.51	9.739
1.8168E 02	41.38	-0.36	-0.52	23.57	7.56	9.801
1.8169E 02	41.23	-0.36	-0.52	23.56	7.56	9.799
1.8170E 02	41.08	-0.36	-0.52	23.87	7.67	9.926
1.8171E 02	40.96	-0.36	-0.51	24.13	7.75	10.028
1.8172E 02	40.79	-0.37	-0.52	24.26	7.79	10.085
1.8173E 02	40.65	-0.37	-0.51	24.14	7.75	10.037
1.8174E 02	40.52	-0.37	-0.53	23.74	7.61	9.873
1.8174E 02	40.37	-0.37	-0.52	23.15	7.42	9.635
1.8175E 02	40.22	-0.36	-0.52	23.18	7.43	9.643
1.8176E 02	40.09	-0.35	-0.50	23.20	7.45	9.647
1.8177E 02	39.95	-0.37	-0.51	23.66	7.59	9.840
1.8178E 02	39.80	-0.37	-0.52	23.85	7.65	9.917
1.8179E 02	39.64	-0.37	-0.51	23.94	7.69	9.952
1.8180E 02	39.52	-0.37	-0.52	23.94	7.68	9.953
1.8181E 02	39.38	-0.36	-0.52	24.07	7.73	10.007
1.8181E 02	39.22	-0.35	-0.52	24.20	7.78	10.060
1.8182E 02	39.10	-0.37	-0.51	24.30	7.81	10.100
1.8183E 02	38.96	-0.36	-0.50	24.30	7.81	10.098
1.8184E 02	38.81	-0.36	-0.52	24.35	7.83	10.121
1.8185E 02	38.68	-0.36	-0.52	24.31	7.81	10.104
1.8186E 02	38.54	-0.35	-0.52	24.35	7.83	10.119
1.8187E 02	38.39	-0.35	-0.52	24.36	7.83	10.121
1.8187E 02	38.26	-0.36	-0.51	24.40	7.84	10.138
1.8188E 02	38.10	-0.35	-0.51	24.32	7.82	10.107
1.8189E 02	37.97	-0.36	-0.51	24.35	7.83	10.117
1.8190E 02	37.83	-0.35	-0.51	24.42	7.85	10.145
1.8191E 02	37.70	-0.35	-0.52	24.38	7.83	10.131
1.8192E 02	37.55	-0.36	-0.52	24.41	7.84	10.143

TABLE 9. TEST NO. 6 - 1/2-IN. BAR STRESS WHILE CYCLING (FULL STRESS CREEP)
(SHEET 6 OF 8)

1.8193E 02			37.40	-0.35	-0.51	24.41	7.85	10.141
1.8193E 02			37.28	-0.36	-0.51	24.28	7.80	10.088
1.8194E 02			37.13	-0.36	-0.52	24.33	7.82	10.112
1.8195E 02			36.99	-0.36	-0.52	24.33	7.82	10.110
1.8196E 02			36.85	-0.35	-0.52	24.36	7.83	10.123
1.8197E 02			36.71	-0.35	-0.53	24.39	7.84	10.136
1.8198E 02			36.56	-0.36	-0.53	24.41	7.84	10.147
1.8199E 02			36.44	-0.36	-0.52	24.21	7.78	10.064
1.8200E 02			36.28	-0.36	-0.51	24.31	7.81	10.103
1.8200E 02			36.13	-0.35	-0.50	24.34	7.83	10.113
1.8201E 02			36.00	-0.35	-0.51	24.42	7.85	10.144
1.8202E 02			35.86	-0.36	-0.51	24.43	7.85	10.150
1.8203E 02			35.72	-0.36	-0.51	24.46	7.86	10.163
1.8204E 02			35.60	-0.36	-0.51	23.89	7.67	9.930
1.8236E 02	74.5	75.9	35.63	-0.36	-0.52	24.74	7.96	10.280
1.8256E 02	74.6	76.2	35.63	-0.35	-0.53	24.94	8.02	10.363
1.8276E 02	74.5	76.2	35.63	-0.35	-0.52	24.96	8.03	10.369
1.8316E 02	74.5	76.0	35.63	-0.36	-0.52	25.15	8.09	10.447
1.8396E 02	74.6	76.2	35.63	-0.37	-0.51	25.09	8.07	10.421
1.8556E 02	74.7	76.4	35.63	-0.35	-0.52	25.01	8.04	10.387
1.8876E 02	74.8	76.2	35.63	-0.35	-0.51	25.20	8.11	10.463
1.9516E 02	75.0	76.8	35.64	-0.34	-0.52	25.17	8.10	10.450
2.0796E 02	75.5	77.0	35.64	-0.31	-0.52	24.85	8.01	10.313
2.3356E 02	75.9	77.6	35.64	-0.31	-0.51	24.75	7.98	10.275
2.8476E 02	75.9	77.4	35.64	-0.25	-0.49	24.23	7.83	10.043
3.6112E 02	76.0	77.5	35.64	-0.26	-0.49	23.84	7.69	9.886
3.6220E 02			32.53	-0.26	-0.50	22.57	7.27	9.370
3.6221E 02			32.40	-0.27	-0.49	21.34	6.86	8.867
3.6222E 02			32.30	-0.28	-0.50	20.34	6.52	8.464
3.6222E 02			32.20	-0.26	-0.50	19.48	6.24	8.106
3.6223E 02			32.08	-0.27	-0.49	18.67	5.97	7.778
3.6224E 02			31.98	-0.28	-0.50	17.97	5.73	7.498
3.6224E 02			31.85	-0.26	-0.51	17.36	5.53	7.244
3.6225E 02			31.76	-0.28	-0.49	16.74	5.32	6.994
3.6226E 02			31.64	-0.27	-0.49	16.19	5.14	6.766
3.6227E 02			31.52	-0.26	-0.50	15.72	4.98	6.572
3.6227E 02			31.38	-0.29	-0.50	15.24	4.82	6.383
3.6228E 02			31.27	-0.27	-0.50	14.74	4.66	6.177
3.6229E 02			31.18	-0.29	-0.50	14.31	4.51	6.006
3.6229E 02			31.06	-0.27	-0.50	13.92	4.39	5.839
3.6230E 02			30.94	-0.27	-0.50	13.51	4.25	5.673
3.6231E 02			30.84	-0.27	-0.50	13.13	4.12	5.520
3.6231E 02			30.72	-0.26	-0.50	12.81	4.02	5.387
3.6232E 02			30.61	-0.29	-0.50	12.49	3.90	5.262
3.6233E 02			30.50	-0.27	-0.49	12.15	3.80	5.116
3.6233E 02			30.39	-0.29	-0.50	11.84	3.68	4.996
3.6234E 02			30.28	-0.26	-0.51	11.57	3.60	4.883
3.6235E 02			30.17	-0.27	-0.50	11.25	3.49	4.750
3.6235E 02			30.06	-0.29	-0.50	10.97	3.40	4.642
3.6236E 02			29.94	-0.27	-0.50	10.73	3.32	4.538
3.6237E 02			29.84	-0.27	-0.50	10.47	3.23	4.434
3.6237E 02			29.72	-0.28	-0.51	10.21	3.14	4.330
3.6238E 02			29.61	-0.26	-0.50	10.00	3.08	4.240
3.6239E 02			29.51	-0.29	-0.50	9.75	2.99	4.142

TABLE 9. TEST NO. 6 - 1/2-IN. BAR STRESS WHILE CYCLING (FULL STRESS CREEP)
(SHEET 7 OF 8)

3.6239E 02	29.39	-0.26	-0.50	9.50	2.91	4.033
3.6240E 02	29.28	-0.26	-0.50	9.29	2.84	3.951
3.6241E 02	29.17	-0.28	-0.49	9.08	2.77	3.863
3.6242E 02	29.06	-0.26	-0.50	8.85	2.70	3.768
3.6242E 02	28.95	-0.28	-0.51	8.65	2.62	3.695
3.6243E 02	28.84	-0.26	-0.50	8.46	2.57	3.611
3.6244E 02	28.72	-0.27	-0.50	8.25	2.50	3.527
3.6244E 02	28.61	-0.28	-0.50	8.05	2.42	3.446
3.6245E 02	28.50	-0.26	-0.50	7.89	2.37	3.377
3.6246E 02	28.39	-0.29	-0.50	7.70	2.30	3.307
3.6246E 02	28.28	-0.26	-0.50	7.52	2.25	3.225
3.6247E 02	28.17	-0.27	-0.50	7.35	2.19	3.159
3.6248E 02	28.06	-0.26	-0.50	7.20	2.15	3.093
3.6248E 02	27.95	-0.27	-0.50	7.01	2.08	3.020
3.6249E 02	27.83	-0.27	-0.49	6.84	2.03	2.947
3.6250E 02	27.71	-0.26	-0.51	6.69	1.97	2.889
3.6250E 02	27.64	-0.30	-0.50	6.52	1.91	2.827
3.6251E 02	27.50	-0.26	-0.51	6.36	1.86	2.754
3.6252E 02	27.25	-0.28	-0.50	6.22	1.81	2.702
3.6252E 02	27.28	-0.26	-0.50	6.08	1.77	2.641
3.6253E 02	27.17	-0.26	-0.50	5.91	1.72	2.570
3.6254E 02	27.13	-0.27	-0.50	5.77	1.67	2.513
3.6255E 02	27.20	-0.26	-0.52	5.64	1.62	2.464
3.6255E 02	29.68	-0.28	-0.51	5.50	1.57	2.406
3.6256E 02	30.76	-0.27	-0.50	5.34	1.53	2.339
3.6257E 02	28.25	-0.29	-0.50	5.21	1.47	2.290
3.6257E 02	28.02	-0.26	-0.51	5.10	1.44	2.241
3.6258E 02	45.90	-0.29	-0.50	4.94	1.39	2.181
3.6259E 02	26.35	-0.26	-0.50	4.82	1.35	2.123
3.6259E 02	41.71	-0.26	-0.50	4.69	1.31	2.071
3.6260E 02	18.41	-0.28	-0.50	4.57	1.26	2.026
3.6261E 02	25.94	-0.27	-0.50	4.43	1.22	1.967
3.6261E 02	55.14	-0.28	-0.50	4.31	1.18	1.922
3.6262E 02	26.95	-0.28	-0.50	4.21	1.14	1.879
3.6263E 02	58.56	-0.27	-0.50	4.06	1.10	1.816
3.6263E 02	68.68	-0.28	-0.51	3.96	1.06	1.779
3.6264E 02	57.15	-0.27	-0.50	3.86	1.03	1.734
3.6265E 02	38.08	-0.27	-0.49	3.72	0.99	1.674
3.6265E 02	61.03	-0.28	-0.50	3.60	0.94	1.633
3.6266E 02	50.83	-0.26	-0.50	3.50	0.92	1.587
3.6267E 02	21.35	-0.26	-0.50	3.36	0.87	1.528
3.6268E 02	56.81	-0.29	-0.50	3.27	0.83	1.496
3.6268E 02	38.27	-0.26	-0.50	3.17	0.80	1.451
3.6269E 02	32.96	-0.27	-0.50	3.04	0.76	1.400
3.6270E 02	34.21	-0.27	-0.50	2.93	0.72	1.353
3.6270E 02	54.70	-0.26	-0.50	2.82	0.68	1.308
3.6271E 02	29.03	-0.29	-0.49	2.71	0.64	1.265
3.6272E 02	30.87	-0.27	-0.50	2.59	0.61	1.218
3.6272E 02	26.59	-0.29	-0.50	2.51	0.57	1.187
3.6273E 02	3.22	-0.26	-0.50	2.41	0.55	1.141
3.6274E 02	57.30	-0.27	-0.49	2.30	0.52	1.098
3.6274E 02	27.64	-0.27	-0.50	2.20	0.48	1.058
3.6275E 02	24.86	-0.26	-0.50	2.10	0.45	1.015
3.6276E 02	22.29	-0.29	-0.50	2.01	0.40	0.983

TABLE 9. TEST NO. 6 - 1/2-IN. BAR STRESS WHILE CYCLING (FULL STRESS CREEP)
(SHEET 8 OF 8)

3.6276E 02	52.82	-0.27	-0.49	1.90	0.38	0.934
3.6277E 02	26.45	-0.28	-0.50	1.81	0.34	0.902
3.6278E 02	21.69	-0.26	-0.51	1.73	0.32	0.870
3.6278E 02	23.88	-0.27	-0.50	1.60	0.28	0.814
3.6279E 02	12.77	-0.29	-0.51	1.52	0.24	0.788
3.6280E 02	24.67	-0.27	-0.51	1.45	0.22	0.753
3.6280E 02	19.36	-0.28	-0.51	1.32	0.18	0.705
3.6281E 02	24.16	-0.27	-0.50	1.23	0.15	0.663
3.6282E 02	22.13	-0.26	-0.51	1.19	0.14	0.649
3.6283E 02	22.14	-0.29	-0.50	1.07	0.10	0.604
3.6283E 02	22.20	-0.27	-0.50	0.96	0.06	0.555
3.6284E 02	22.10	-0.29	-0.51	0.92	0.04	0.542
3.6285E 02	22.02	-0.26	-0.50	0.85	0.03	0.510
3.6285E 02	21.88	-0.27	-0.50	0.70	-0.02	0.448
3.6286E 02	21.80	-0.27	-0.50	0.61	-0.05	0.414
3.6287E 02	21.53	-0.26	-0.51	0.60	-0.06	0.413
3.6287E 02	21.58	-0.27	-0.51	0.50	-0.10	0.372
3.6288E 02	21.06	-0.27	-0.50	0.41	-0.12	0.335
3.6289E 02	21.09	-0.29	-0.51	0.35	-0.15	0.315
3.6289E 02	21.20	-0.26	-0.50	0.28	-0.16	0.282
3.6290E 02	21.13	-0.27	-0.49	0.18	-0.19	0.242
3.6291E 02	20.98	-0.27	-0.50	0.07	-0.23	0.204

TABLE 10. FULL STRESS CREEP TEST FOR UTP-19,360B-400/1777 at 71°F

T8710

Time, min.	Cathetometer Strain, %				Stress $F(A_o)$, psi				$\lambda \sigma$, psi	Secant Modulus, psi
	No. 1	No. 2	No. 3	Average	No. 1	No. 2	No. 3	Average		
0.0066				0.01	0	0	0	0	0	-
0.1218				2.03	0	2.80	0	0	0	-
0.2377				3.96	6.21	11.41	8.95	8.95	9.30	235
0.3338				5.56	12.46	16.66	15.18	15.18	16.02	288
0.4643				7.74	22.43	26.24	26.32	26.32	28.36	366
0.5810				9.68	30.33	33.87	34.84	34.84	38.21	395
0.6979				11.63	37.42	40.52	42.61	42.61	47.57	409
0.8146				13.58	43.53	45.80	46.30	46.30	52.59	387
0.9261				15.44				46.34	53.49	346
5	Broke	Broke	20.43	20.43				47.50	57.20	280
18.557				24.20			47.53	47.52	59.02	244
30			25.64	25.64				47.42	59.58	232
56.958				27.80			47.32	47.32	60.47	218
90			29.81	29.81				47.39	61.52	206
108.16				30.70			47.46	47.40	61.95	202
150				32.40				47.46	62.84	194
180			33.64	32.64				47.46	63.43	189
181.78				32.78			23.85	23.85	31.67	96.6
183.16				32.12			25.15	25.15	33.23	103.4
185			31.23	31.25				25.00	32.81	105.1
215			31.00	31.00				24.90	32.62	105.2
233.56				30.90			24.75	24.75	32.40	104.8
275			30.76	30.76				24.00	31.38	102.0
284.76				30.78			24.23	24.23	31.69	102.9
360			30.83	30.83			24.23	24.23	31.70	102.8
363.26				12.00			-	-		
363.32				10.00			-	-		
365			7.96	7.96			0	0		
390			4.61	4.61			0	0		
480			2.91	2.91			0	0		
1290			1.15	1.15			0	0		

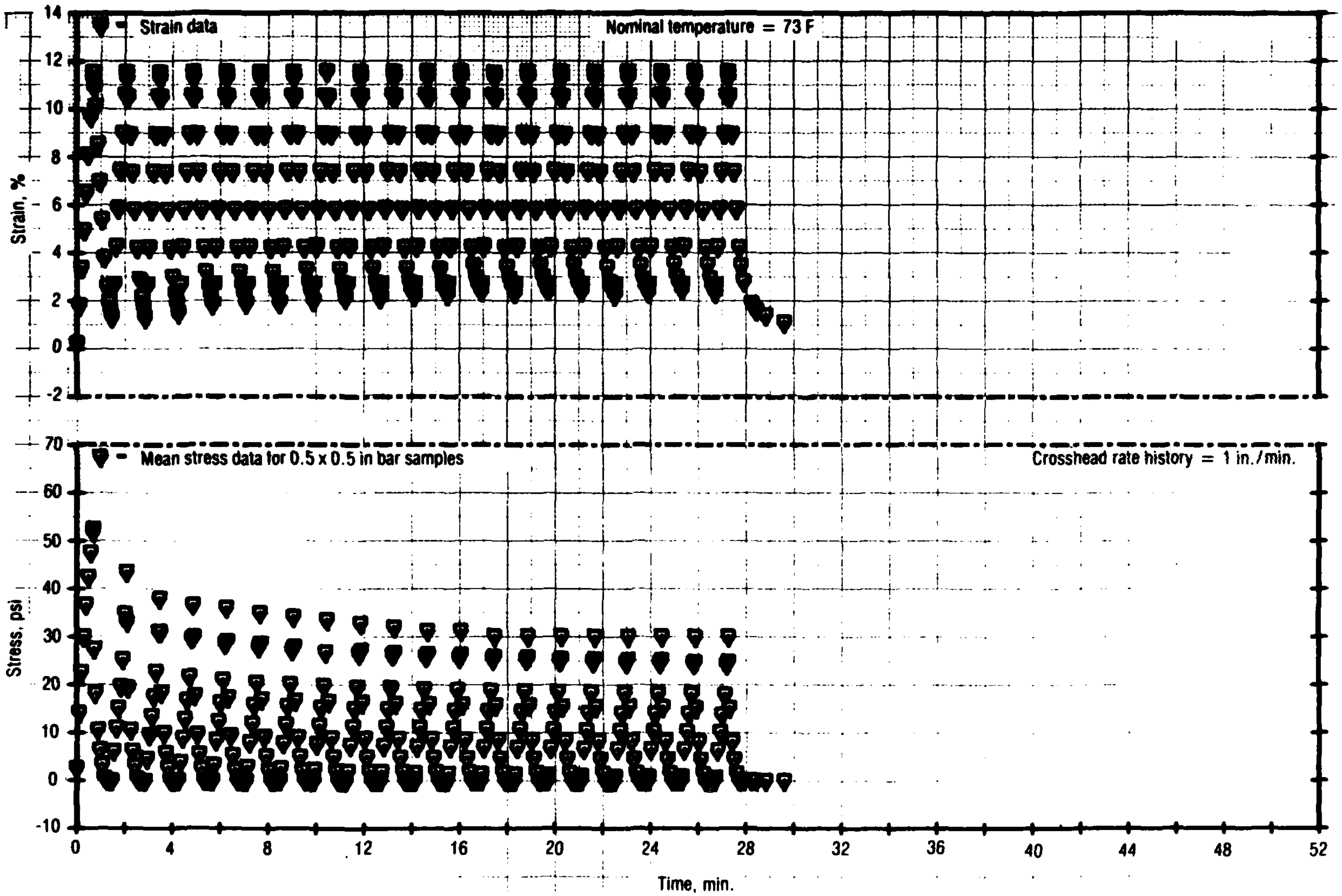

Figure 22. Test No. 7 - Stress While Cycling for UTP-19,360B-400/1777

28754

TABLE 11. TEST NO. 7 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 1 OF 7)

PROPELLANT: UTP 19360B 400/1777
REQUESTOR: Carlton
WOR:

DATE: 6/4/81
OPERATOR: JWD

DEFINITIONS:
Time = Time From Start of Test (min)
= Stress (psi)
= Strain (%)
T(air) = Test Air Temperature (F)
T(prop) = Test Propellant Temperature (F)

RELATIONSHIPS:
= Force/Area
= Sample Extension/Length

NOMINAL VALUES:
Test Temp = 73 F
Gage Length = 6.00 in
Nom. Strain = 12 %
XHD Rate = 1 in/min

CALIBRATION DATA:
Cal Wt = 5.0 lbs

	SAMPLE 1	SAMPLE 2	SAMPLE 3
Load Cal (lbs/volts)	5.855	6.103	6.125
Offset (volts)	0.022	-0.024	0.073
Pot Cal (in/volts) =	-0.389		
Temp (F) =	73.5		
AREAS (sq in):	0.249	0.250	0.250

STRESS DATA (psi):

SET	Time	T(prop)	T(air)	Strain	SAMPLE 1	SAMPLE 2	SAMPLE 3	Avg	St Dev
1	0.01390	75.1	74.7	0.23	2.42	2.22	3.11	2.59	0.330
2	0.11045	75.0	74.9	1.81	14.13	12.74	15.66	14.18	1.033
3	0.20626	74.8	74.7	3.39	22.69	20.34	24.92	22.65	1.618
4	0.30189	74.7	74.9	4.96	30.16	27.05	32.93	30.04	2.080
5	0.39814	75.0	74.5	6.54	36.86	33.19	40.00	36.68	2.411
6	0.49390	74.7	74.5	8.11	42.65	38.72	46.14	42.50	2.623
7	0.59014	74.7	74.5	9.70	47.69	43.67	51.38	47.58	2.730
8	0.68604	74.6	74.8	11.28	51.86	47.95	55.72	51.84	2.747
9	0.70166			11.54	52.54	48.64	56.42	52.54	2.750
10	0.73961	74.8	74.6	10.92	27.16	25.82	29.59	27.52	1.353
11	0.78757	74.9	74.7	10.14	17.72	17.22	19.86	18.27	0.992
12	0.88419	75.0	75.2	8.55	10.11	9.98	11.72	10.60	0.686
13	0.98001	74.6	74.5	6.99	6.05	5.99	7.28	6.44	0.514
14	1.07548	75.1	74.6	5.41	3.00	2.98	3.91	3.30	0.374
15	1.17194	74.7	74.8	3.82	0.40	0.42	0.97	0.60	0.228
16	1.26789	75.0	74.7	2.60	0.00	0.00	0.00	0.00	0.000
17	1.36400	75.1	74.8	1.95	0.00	0.00	0.00	0.00	0.000
18	1.41874			1.60	0.00	0.00	0.00	0.00	0.000
19	1.47500	74.8	74.4	1.32	0.00	0.00	0.00	0.00	0.000
20	1.56331	74.9	74.8	2.71	5.91	5.65	7.05	6.20	0.525
21	1.65919	74.7	74.4	4.29	10.72	10.26	12.17	11.05	0.705
22	1.75488	74.8	74.1	5.86	14.82	14.17	16.60	15.19	0.890
23	1.85128	74.6	74.1	7.45	19.21	18.36	21.36	19.64	1.093
24	1.94690	74.4	74.2	9.01	24.83	23.65	27.45	25.31	1.377
25	2.04269	74.5	74.0	10.59	34.34	32.41	37.73	34.83	1.901
26	2.10017			11.54	42.99	40.63	46.84	43.49	2.217

TABLE 11. TEST NO. 7 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 2 OF 7)

27	2.11481	74.5	74.6	11.30	33.05	30.81	35.31	33.06	1.591
28	2.16277	74.8	74.1	10.52	18.87	18.25	21.06	19.39	1.044
29	2.25948	74.9	74.1	8.94	10.13	9.95	11.71	10.60	0.685
30	2.35539	74.4	74.3	7.37	5.85	5.80	7.08	6.24	0.513
31	2.45086	75.0	74.2	5.80	2.87	2.80	3.73	3.13	0.364
32	2.54730	74.7	74.5	4.21	0.25	0.28	0.82	0.45	0.226
33	2.64284	74.3	74.3	2.90	0.00	0.00	0.00	0.00	0.000
34	2.73930	75.3	74.1	2.15	0.00	0.00	0.00	0.00	0.000
35	2.81435			1.70	0.00	0.00	0.00	0.00	0.000
36	2.87500	74.4	74.0	1.30	0.00	0.00	0.00	0.00	0.000
37	2.95881	74.8	73.9	2.66	4.32	4.15	5.46	4.64	0.502
38	3.05468	74.4	73.6	4.24	9.24	8.85	10.60	9.56	0.652
39	3.15045	74.3	74.3	5.82	13.15	12.64	14.85	13.55	0.818
40	3.24691	74.8	74.0	7.40	17.22	16.55	19.27	17.68	1.002
41	3.34239	74.1	74.2	8.96	22.26	21.33	24.72	22.77	1.237
42	3.43826	74.3	74.2	10.54	30.49	28.97	33.65	31.04	1.686
43	3.49863			11.53	37.43	35.54	41.03	38.00	1.972
44	3.51297	74.1	74.1	11.30	31.07	28.96	33.28	31.10	1.526
45	3.56092	74.4	73.8	10.52	17.90	17.31	20.02	18.41	1.009
46	3.65749	74.3	74.0	8.94	9.52	9.40	11.10	10.01	0.671
47	3.75340	74.7	73.7	7.37	5.44	5.37	6.59	5.80	0.484
48	3.84890	74.3	74.0	5.79	2.46	2.43	3.30	2.73	0.350
49	3.94531	74.7	74.0	4.21	0.00	0.00	0.44	0.15	0.180
50	4.04099	74.4	73.8	3.00	0.00	0.00	0.00	0.00	0.000
51	4.13752	74.6	74.0	2.28	0.00	0.00	0.00	0.00	0.000
52	4.21243			1.87	0.00	0.00	0.00	0.00	0.000
53	4.28000	74.7	73.9	1.50	0.00	0.00	0.00	0.00	0.000
54	4.35692	75.1	74.2	2.66	3.51	3.38	4.70	3.86	0.516
55	4.45289	74.6	74.0	4.24	8.56	8.22	9.89	8.89	0.624
56	4.54853	74.6	74.1	5.82	12.43	11.98	14.07	12.83	0.778
57	4.64484	74.3	74.1	7.40	16.41	15.78	18.36	16.85	0.951
58	4.74062	74.4	74.0	8.96	21.15	20.34	23.56	21.69	1.184
59	4.83701	74.1	74.0	10.55	28.98	27.59	32.03	29.53	1.604
60	4.89697			11.54	36.01	34.26	39.45	36.57	1.867
61	4.91112	74.2	74.1	11.31	29.91	27.90	32.09	29.97	1.482
62	4.95976	74.2	73.8	10.52	17.19	16.64	19.29	17.71	0.986
63	5.05560	74.3	74.1	8.95	9.18	9.05	10.73	9.66	0.660
64	5.15142	74.0	74.2	7.38	5.12	5.07	6.29	5.50	0.489
65	5.24701	74.8	73.9	5.80	2.21	2.17	3.04	2.47	0.345
66	5.34347	74.2	73.7	4.21	0.00	0.00	0.22	0.07	0.088
67	5.43924	74.4	74.1	3.20	0.00	0.00	0.00	0.00	0.000
68	5.53560	74.6	73.7	2.55	0.00	0.00	0.00	0.00	0.000
69	5.61057			2.20	0.00	0.00	0.00	0.00	0.000
70	5.70000	74.1	74.3	1.85	0.00	0.00	0.00	0.00	0.000
71	5.75445	74.7	73.8	2.65	2.86	2.79	4.13	3.26	0.534
72	5.85047	74.3	73.9	4.24	8.07	7.74	9.40	8.40	0.621
73	5.94693	74.1	74.1	5.83	11.97	11.52	13.59	12.36	0.773
74	6.04249	74.0	74.5	7.40	15.79	15.21	17.76	16.26	0.943
75	6.13886	73.9	74.2	8.96	20.52	19.71	22.85	21.03	1.154
76	6.23455	74.5	74.4	10.54	27.93	26.62	30.90	28.48	1.550
77	6.29496			11.54	35.42	33.80	38.79	36.00	1.800
78	6.30962	73.9	74.0	11.30	29.00	27.04	31.11	29.05	1.440
79	6.35791	74.2	74.0	10.52	16.79	16.26	18.86	17.30	0.970
80	6.45403	73.9	74.3	8.95	8.96	8.82	10.47	9.42	0.647
81	6.54989	74.4	74.0	7.38	4.96	4.89	6.09	5.31	0.476
82	6.64554	74.6	74.6	5.80	1.98	1.98	2.83	2.26	0.347
83	6.74190	74.4	74.5	4.21	0.00	0.00	0.00	0.00	0.000
84	6.83785	74.4	74.0	3.20	0.00	0.00	0.00	0.00	0.000

TABLE 11. TEST NO. 7 - 1/2-IN. BAR STRESS WHILE CYCLING (SHEET 3 OF 7)

85	6.93397	74.2	74.0	2.60	0.00	0.00	0.00	0.00	0.000
86	7.00896			2.25	0.00	0.00	0.00	0.00	0.000
87	7.10500	74.8	74.1	1.90	0.00	0.00	0.00	0.00	0.000
88	7.15344	74.1	74.3	2.67	2.53	2.46	3.81	2.94	0.538
89	7.24920	74.4	74.3	4.25	7.71	7.46	9.07	8.08	0.610
90	7.34498	74.3	74.2	5.83	11.63	11.20	13.21	12.01	0.750
91	7.44151	73.8	74.3	7.41	15.43	14.88	17.37	15.90	0.923
92	7.53702	74.1	74.2	8.96	20.00	19.25	22.32	20.52	1.131
93	7.63346	74.0	74.2	10.55	27.30	26.04	30.22	27.85	1.513
94	7.69377			11.55	34.42	32.85	37.72	35.00	1.758
95	7.70754	73.9	74.2	11.32	28.56	26.61	30.65	28.61	1.426
96	7.75614	73.9	74.4	10.53	16.52	15.97	18.54	17.01	0.959
97	7.85214	74.4	74.2	8.95	8.80	8.64	10.29	9.24	0.643
98	7.94811	73.9	74.7	7.38	4.77	4.72	5.92	5.13	0.480
99	8.04349	74.2	74.2	5.81	1.93	1.88	2.72	2.17	0.333
100	8.14019	74.1	74.9	4.21	0.00	0.00	0.00	0.00	0.000
101	8.23572	74.2	74.5	3.20	0.00	0.00	0.00	0.00	0.000
102	8.33205	74.6	74.5	2.62	0.00	0.00	0.00	0.00	0.000
103	8.40704			2.30	0.00	0.00	0.00	0.00	0.000
104	8.51000	74.2	74.5	1.90	0.00	0.00	0.00	0.00	0.000
105	8.55146	74.6	74.6	2.67	2.13	2.11	3.47	2.57	0.553
106	8.64733	74.2	74.6	4.25	7.44	7.19	8.78	7.80	0.606
107	8.74311	74.0	74.7	5.82	11.31	10.91	12.91	11.71	0.747
108	8.83951	74.0	74.7	7.40	15.11	14.57	17.01	15.57	0.908
109	8.93514	73.9	74.2	8.95	19.60	18.87	21.88	20.12	1.112
110	9.03092	73.8	75.0	10.53	26.67	25.42	29.50	27.20	1.478
111	9.09123			11.52	33.58	32.01	36.76	34.12	1.711
112	9.10643	73.8	74.5	11.31	27.86	25.95	29.91	27.91	1.399
113	9.15509	74.0	74.7	10.52	16.18	15.65	18.19	16.67	0.946
114	9.25039	73.9	74.3	8.96	8.62	8.49	10.13	9.08	0.645
115	9.34676	74.4	74.4	7.38	4.65	4.61	5.79	5.02	0.472
116	9.44235	73.9	74.3	5.81	1.79	1.78	2.59	2.05	0.330
117	9.53910	74.6	73.8	4.21	0.00	0.00	0.00	0.00	0.000
118	9.63465	74.0	74.9	3.30	0.00	0.00	0.00	0.00	0.000
119	9.73094	74.2	74.6	2.70	0.00	0.00	0.00	0.00	0.000
120	9.80593			2.35	0.00	0.00	0.00	0.00	0.000
121	9.91500	74.2	74.7	2.00	0.00	0.00	0.00	0.00	0.000
122	9.95048	74.1	74.2	2.68	1.82	1.90	3.28	2.33	0.580
123	10.04582	74.2	74.4	4.26	7.25	6.99	8.57	7.60	0.601
124	10.04910			4.31	7.43	7.16	8.76	7.78	0.602
125	10.14221	74.5	74.3	5.84	11.15	10.72	12.70	11.52	0.735
126	10.23784	73.9	74.6	7.41	14.86	14.32	16.73	15.31	0.895
127	10.33421	73.8	74.7	8.97	19.36	18.61	21.59	19.85	1.096
128	10.42986	74.0	74.7	10.54	26.28	25.05	29.06	26.80	1.452
129	10.49080	74.0	74.9	11.56	33.43	31.59	35.47	33.50	1.372
130	10.55307	73.8	74.7	10.53	16.06	15.50	18.02	16.52	0.935
131	10.64936	74.5	74.6	8.95	8.48	8.34	9.96	8.93	0.637
132	10.74538	73.9	75.0	7.38	4.54	4.49	5.68	4.90	0.476
133	10.84069	74.5	74.6	5.81	1.69	1.68	2.50	1.96	0.335
134	10.93724	74.2	74.7	4.21	0.00	0.00	0.00	0.00	0.000
135	11.03288	74.1	74.7	3.30	0.00	0.00	0.00	0.00	0.000
136	11.12929	74.8	74.4	2.75	0.00	0.00	0.00	0.00	0.000
137	11.20429			2.40	0.00	0.00	0.00	0.00	0.000
138	11.25239	74.2	74.6	2.10	0.00	0.00	0.00	0.00	0.000
139	11.34873	74.2	75.1	2.67	1.40	1.65	3.06	2.04	0.629
140	11.44469	74.5	74.6	4.26	7.09	6.84	8.42	7.45	0.598
141	11.54055	74.1	74.6	5.84	10.96	10.54	12.51	11.34	0.731
142	11.63619	74.4	74.7	7.40	14.68	14.12	16.51	15.10	0.883
143	11.73218	74.1	74.8	8.97	19.05	18.32	21.26	19.54	1.083

TABLE 11. TEST NO. 7 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 4 OF 7)

144	11.82882	73.9	75.1	10.56	25.97	24.73	28.71	26.47	1.437
145	11.88950			11.56	32.29	30.74	35.35	32.79	1.659
146	11.90299	73.9	75.1	11.33	27.14	25.27	29.14	27.19	1.367
147	11.95130	73.9	75.0	10.54	15.87	15.33	17.83	16.34	0.929
148	12.04753	74.1	74.5	8.96	8.44	8.26	9.88	8.86	0.628
149	12.14306	74.4	75.2	7.39	4.56	4.45	5.63	4.88	0.462
150	12.23947	74.0	74.9	5.80	1.66	1.61	2.43	1.90	0.328
151	12.33539	74.4	75.2	4.22	0.00	0.00	0.00	0.00	0.000
152	12.43107	74.3	75.0	3.35	0.00	0.00	0.00	0.00	0.000
153	12.52735	74.1	74.9	2.75	0.00	0.00	0.00	0.00	0.000
154	12.60320			2.45	0.00	0.00	0.00	0.00	0.000
155	12.71000	74.5	75.0	2.10	0.00	0.00	0.00	0.00	0.000
156	12.74769	74.7	75.2	2.68	1.22	1.51	2.92	1.88	0.644
157	12.84375	74.0	74.9	4.27	6.91	6.72	8.27	7.30	0.599
158	12.93927	74.4	75.1	5.84	10.79	10.39	12.33	11.17	0.724
159	13.03580	74.1	74.8	7.42	14.50	13.97	16.34	14.94	0.878
160	13.13133	74.1	74.9	8.98	18.87	18.13	21.03	19.34	1.066
161	13.22707	74.2	74.8	10.56	25.69	24.42	28.33	26.15	1.409
162	13.28710			11.55	31.53	29.94	34.48	31.98	1.629
163	13.30195	74.4	75.2	11.31	26.59	24.78	28.56	26.65	1.338
164	13.35050	73.9	75.1	10.52	15.63	15.10	17.56	16.09	0.917
165	13.44644	74.4	74.8	8.95	8.30	8.15	9.76	8.74	0.628
166	13.54233	74.1	74.9	7.38	4.39	4.40	5.55	4.78	0.472
167	13.63783	74.5	75.0	5.81	1.52	1.59	2.38	1.83	0.339
168	13.73444	74.4	75.2	4.21	0.00	0.00	0.00	0.00	0.000
169	13.83016	74.1	75.1	3.33	0.00	0.00	0.00	0.00	0.000
170	13.92664	75.1	74.6	2.77	0.00	0.00	0.00	0.00	0.000
171	14.00135			2.43	0.00	0.00	0.00	0.00	0.000
172	14.15000	74.4	74.7	2.21	0.00	0.00	0.00	0.00	0.000
173	14.14542	74.3	74.6	2.67	0.82	1.32	2.70	1.62	0.690
174	14.24139	74.5	75.6	4.26	6.71	6.56	8.09	7.12	0.598
175	14.33795	74.2	74.6	5.85	10.64	10.27	12.19	11.03	0.718
176	14.43344	74.7	75.1	7.41	14.33	13.81	16.14	14.76	0.865
177	14.52979	74.2	75.3	8.98	18.60	17.97	20.82	19.13	1.059
178	14.62550	74.2	75.0	10.56	25.31	24.17	28.01	25.83	1.392
179	14.68590			11.55	30.73	29.26	33.72	31.24	1.607
180	14.70030	74.1	75.0	11.32	26.31	24.56	28.29	26.39	1.319
181	14.74876	74.6	74.8	10.53	15.54	14.99	17.44	15.99	0.910
182	14.84425	74.2	75.2	8.96	8.21	8.09	9.69	8.66	0.632
183	14.94072	74.6	75.1	7.38	4.39	4.31	5.48	4.73	0.463
184	15.03625	74.2	75.2	5.81	1.48	1.53	2.33	1.78	0.336
185	15.13294	74.5	75.1	4.21	0.00	0.00	0.00	0.00	0.000
186	15.22862	74.9	75.2	3.33	0.00	0.00	0.00	0.00	0.000
187	15.32469	74.2	75.1	2.77	0.00	0.00	0.00	0.00	0.000
188	15.39979			2.47	0.00	0.00	0.00	0.00	0.000
189	15.51500	74.7	75.2	2.26	0.00	0.00	0.00	0.00	0.000
190	15.54430	74.8	75.2	2.68	0.76	1.19	2.61	1.52	0.684
191	15.64030	74.3	75.0	4.27	6.65	6.46	7.99	7.03	0.589
192	15.73604	74.7	75.1	5.84	10.53	10.12	12.04	10.89	0.715
193	15.83234	74.4	74.7	7.42	14.24	13.67	16.00	14.64	0.861
194	15.92787	74.5	74.8	8.98	18.52	17.76	20.62	18.97	1.048
195	16.02418	74.2	75.5	10.56	25.15	23.90	27.74	25.60	1.385
196	16.08450			11.56	30.77	29.22	33.67	31.22	1.597
197	16.09850	74.4	75.4	11.32	26.30	24.39	28.12	26.27	1.319
198	16.14673	74.2	74.8	10.54	15.46	14.89	17.34	15.90	0.907
199	16.24302	74.4	75.3	8.95	8.15	8.00	9.59	8.58	0.623
200	16.33883	74.1	75.6	7.38	4.31	4.25	5.42	4.66	0.466
201	16.43505	74.8	75.0	5.80	1.49	1.43	2.25	1.73	0.324

TABLE 11. TEST NO. 7 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 5 OF 7)

202	16.53098	74.6	75.1	4.22	0.00	0.00	0.00	0.00	0.000
203	16.62725	74.4	75.4	3.45	0.00	0.00	0.00	0.00	0.000
204	16.72293	74.6	75.1	2.95	0.00	0.00	0.00	0.00	0.000
205	16.79781			2.65	0.00	0.00	0.00	0.00	0.000
206	16.92500	74.4	75.1	2.40	0.00	0.00	0.00	0.00	0.000
207	16.94222	74.5	75.4	2.67	0.55	1.02	2.45	1.34	0.698
208	17.03820	74.8	75.0	4.26	6.52	6.33	7.85	6.90	0.585
209	17.13393	74.4	75.2	5.83	10.41	9.99	11.89	10.76	0.708
210	17.23040	74.5	75.1	7.42	14.12	13.53	15.85	14.50	0.854
211	17.32580	74.3	75.0	8.97	18.32	17.56	20.40	18.76	1.039
212	17.42168	74.5	75.2	10.55	24.86	23.60	27.39	25.29	1.364
213	17.48000			11.50	29.69	28.27	32.36	30.11	1.468
214	17.49716	74.3	75.4	11.32	25.93	24.04	27.73	25.90	1.304
215	17.54568	74.4	75.3	10.53	15.33	14.72	17.15	15.73	0.892
216	17.64112	74.4	74.8	8.96	8.15	7.95	9.55	8.55	0.614
217	17.73739	74.4	75.3	7.38	4.27	4.20	5.36	4.61	0.461
218	17.83309	74.5	74.6	5.81	1.45	1.39	2.22	1.69	0.329
219	17.92978	74.6	74.4	4.21	0.00	0.00	0.00	0.00	0.000
220	18.02555	74.9	75.3	3.40	0.00	0.00	0.00	0.00	0.000
221	18.12191	74.6	75.0	2.90	0.00	0.00	0.00	0.00	0.000
222	18.19689			2.62	0.00	0.00	0.00	0.00	0.000
223	18.32000	74.3	75.5	2.34	0.00	0.00	0.00	0.00	0.000
224	18.34145	75.2	75.2	2.68	0.52	0.99	2.41	1.30	0.695
225	18.43719	74.5	75.4	4.27	6.50	6.28	7.79	6.86	0.578
226	18.53309	75.0	74.8	5.84	10.35	9.94	11.81	10.70	0.697
227	18.62940	74.6	75.4	7.42	13.98	13.44	15.73	14.39	0.846
228	18.72484	74.6	75.3	8.98	18.22	17.47	20.27	18.65	1.027
229	18.82146	74.6	75.5	10.57	24.84	23.54	27.32	25.23	1.357
230	18.88100			11.55	29.76	28.12	32.49	30.12	1.561
231	18.89557	74.6	75.4	11.32	25.78	23.85	27.51	25.71	1.295
232	18.94364	74.3	75.6	10.54	15.29	14.67	17.09	15.68	0.888
233	19.04008	74.5	75.4	8.95	8.02	7.86	9.44	8.44	0.616
234	19.13579	74.5	75.6	7.38	4.28	4.16	5.33	4.59	0.454
235	19.23203	74.7	75.4	5.80	1.37	1.33	2.15	1.62	0.329
236	19.32799	74.8	75.6	4.22	0.00	0.00	0.00	0.00	0.000
237	19.42369	74.6	75.4	3.48	0.00	0.00	0.00	0.00	0.000
238	19.51984	75.4	75.4	3.00	0.00	0.00	0.00	0.00	0.000
239	19.59483			2.70	0.00	0.00	0.00	0.00	0.000
240	19.72500	74.7	75.6	2.42	0.00	0.00	0.00	0.00	0.000
241	19.73919	74.9	75.4	2.67	0.24	0.84	2.24	1.11	0.728
242	19.83509	75.2	75.3	4.26	6.36	6.17	7.68	6.74	0.579
243	19.93079	74.5	75.5	5.84	10.20	9.82	11.68	10.56	0.696
244	20.02729	74.7	75.3	7.42	13.84	13.30	15.58	14.24	0.844
245	20.12278	74.5	75.8	8.98	18.05	17.31	20.10	18.48	1.021
246	20.21873	74.8	75.2	10.55	24.50	23.24	26.98	24.91	1.344
247	20.27960			11.55	29.73	28.15	32.48	30.12	1.549
248	20.29423	74.6	75.7	11.31	25.38	23.53	27.15	25.35	1.282
249	20.34264	74.7	75.5	10.52	15.06	14.48	16.87	15.47	0.885
250	20.43887	74.6	75.8	8.94	7.95	7.78	9.35	8.36	0.612
251	20.53459	74.9	74.8	7.37	4.21	4.11	5.27	4.53	0.454
252	20.63031	74.8	75.6	5.80	1.35	1.31	2.12	1.60	0.323
253	20.72679	74.6	75.7	4.21	0.00	0.00	0.00	0.00	0.000
254	20.82248	75.5	75.1	3.50	0.00	0.00	0.00	0.00	0.000
255	20.91873	74.6	75.9	3.00	0.00	0.00	0.00	0.00	0.000
256	20.99304			2.70	0.00	0.00	0.00	0.00	0.000
257	21.12000	74.9	75.7	2.40	0.00	0.00	0.00	0.00	0.000
258	21.13726	75.2	75.4	2.67	0.16	0.75	2.14	1.02	0.719
259	21.23302	74.8	75.7	4.25	6.24	6.07	7.57	6.63	0.580

TABLE 11. TEST NO. 7 - 1/2-IN. BAR STRESS WHILE CYCLING (SHEET 6 OF 7)

260	21.32892	75.5	75.6	5.83	10.14	9.72	11.59	10.48	0.694
261	21.42515	74.6	75.6	7.41	13.75	13.20	15.47	14.14	0.839
262	21.52089	74.9	75.6	8.97	17.96	17.18	19.96	18.37	1.015
263	21.61728	74.8	75.6	10.56	24.39	23.11	26.83	24.77	1.335
264	21.67720			11.54	29.67	28.09	32.38	30.05	1.534
265	21.69223	74.9	75.6	11.32	25.39	23.49	27.11	25.33	1.281
266	21.74054	74.6	75.8	10.53	15.02	14.43	16.82	15.42	0.882
267	21.83680	74.9	75.8	8.95	7.93	7.75	9.33	8.34	0.612
268	21.93264	74.9	75.9	7.38	4.15	4.07	5.22	4.48	0.456
269	22.02822	75.0	75.2	5.81	1.34	1.30	2.11	1.58	0.320
270	22.12478	74.9	75.9	4.21	0.00	0.00	0.00	0.00	0.000
271	22.22039	74.9	75.2	3.40	0.00	0.00	0.00	0.00	0.000
272	22.31663	74.9	76.0	2.80	0.00	0.00	0.00	0.00	0.000
273	22.39170			2.50	0.00	0.00	0.00	0.00	0.000
274	22.51000	74.9	75.8	2.25	0.00	0.00	0.00	0.00	0.000
275	22.53552	74.9	75.4	2.67	0.05	0.66	2.04	0.92	0.723
276	22.63204	75.5	75.7	4.27	6.25	6.05	7.53	6.61	0.569
277	22.72804	74.8	76.1	5.84	10.05	9.67	11.52	10.41	0.689
278	22.82362	75.0	75.8	7.41	13.64	13.11	15.36	14.04	0.833
279	22.91980	74.9	75.8	8.98	17.85	17.08	19.86	18.26	1.014
280	23.01562	74.7	75.8	10.56	24.18	22.94	26.64	24.59	1.331
281	23.07600			11.55	29.65	28.11	32.39	30.05	1.533
282	23.09033	74.8	75.7	11.32	25.24	23.36	26.98	25.19	1.278
283	23.13834	74.7	75.9	10.54	14.96	14.38	16.78	15.37	0.885
284	23.23424	74.8	75.6	8.96	7.98	7.76	9.33	8.36	0.602
285	23.33056	75.2	75.8	7.38	4.18	4.07	5.21	4.49	0.444
286	23.42624	75.0	75.7	5.81	1.30	1.28	2.08	1.56	0.322
287	23.52289	74.9	75.7	4.21	0.00	0.00	0.00	0.00	0.000
288	23.61858	75.2	75.5	3.45	0.00	0.00	0.00	0.00	0.000
289	23.71474	74.7	75.7	2.90	0.00	0.00	0.00	0.00	0.000
290	23.78978			2.58	0.00	0.00	0.00	0.00	0.000
291	23.91500	74.9	75.6	2.35	0.00	0.00	0.00	0.00	0.000
292	23.93359	75.5	75.6	2.66	0.00	0.59	1.95	0.85	0.707
293	24.02999	74.9	75.9	4.26	6.12	5.97	7.44	6.51	0.573
294	24.12597	75.4	75.3	5.84	9.99	9.59	11.43	10.34	0.686
295	24.22219	74.8	75.9	7.42	13.62	13.05	15.30	13.99	0.827
296	24.31784	75.0	75.9	8.98	17.72	16.97	19.73	18.14	1.008
297	24.41432	75.2	75.1	10.57	24.13	22.84	26.53	24.50	1.324
298	24.47350			11.54	29.71	28.09	32.35	30.05	1.520
299	24.48836	75.0	75.7	11.32	25.17	23.29	26.89	25.12	1.272
300	24.53633	74.8	75.7	10.54	14.96	14.34	16.73	15.34	0.876
301	24.63261	75.5	75.4	8.96	7.93	7.71	9.28	8.30	0.600
302	24.72859	74.9	75.9	7.39	4.11	4.04	5.18	4.44	0.453
303	24.82492	75.4	76.0	5.80	1.27	1.24	2.04	1.51	0.320
304	24.92071	75.2	75.8	4.22	0.00	0.00	0.00	0.00	0.000
305	25.01712	75.0	75.9	3.52	0.00	0.00	0.00	0.00	0.000
306	25.11265	75.9	76.0	3.00	0.00	0.00	0.00	0.00	0.000
307	25.18846			2.75	0.00	0.00	0.00	0.00	0.000
308	25.32000	75.6	76.0	2.45	0.00	0.00	0.00	0.00	0.000
309	25.33294	75.0	76.0	2.68	0.01	0.59	1.99	0.86	0.720
310	25.42902	75.5	76.1	4.27	6.08	5.92	7.42	6.47	0.582
311	25.52453	74.9	75.8	5.84	9.90	9.52	11.37	10.26	0.692
312	25.62101	75.4	76.0	7.43	13.52	12.97	15.23	13.91	0.831
313	25.71635	75.2	75.8	8.98	17.70	16.90	19.65	18.08	1.001
314	25.81302	74.9	75.7	10.57	24.02	22.74	26.42	24.40	1.320
315	25.87250			11.55	29.64	28.06	32.31	30.00	1.519
316	25.88722	74.9	76.0	11.31	24.83	22.95	26.53	24.77	1.268
317	25.93524	75.3	75.7	10.53	14.81	14.18	16.57	15.19	0.875

TABLE 11. TEST NO. 7 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 7 OF 7)

318	26.03169	75.0	76.1	8.95	7.84	7.62	9.20	8.22	0.604
319	26.12743	75.4	75.5	7.38	4.11	3.99	5.14	4.41	0.448
320	26.22311	75.3	76.4	5.81	1.25	1.22	2.02	1.50	0.322
321	26.31954	75.1	76.0	4.21	0.00	0.00	0.00	0.00	0.000
322	26.41529	75.3	75.6	3.50	0.00	0.00	0.00	0.00	0.000
323	26.51144	75.1	75.5	2.95	0.00	0.00	0.00	0.00	0.000
324	26.58651			2.60	0.00	0.00	0.00	0.00	0.000
325	26.71000	75.2	76.1	2.35	0.00	0.00	0.00	0.00	0.000
326	26.73037	75.4	76.1	2.66	0.00	0.46	1.81	0.76	0.665
327	26.82699	75.1	75.9	4.26	6.00	5.86	7.33	6.40	0.575
328	26.92276	75.5	75.5	5.84	9.87	9.47	11.31	10.22	0.685
329	27.01835	74.9	75.8	7.41	13.44	12.89	15.13	13.82	0.825
330	27.11455	75.2	76.1	8.98	17.55	16.81	19.55	17.97	1.004
331	27.21046	75.1	75.8	10.55	23.78	22.56	26.20	24.18	1.312
332	27.27070			11.55	29.61	28.09	32.30	30.00	1.507
333	27.28527	75.2	75.8	11.32	24.86	23.00	26.58	24.81	1.267
334	27.33329	74.9	75.7	10.54	14.80	14.18	16.55	15.18	0.871
335	27.42983	75.4	75.9	8.95	7.77	7.60	9.16	8.18	0.605
336	27.52576	75.1	75.8	7.38	4.09	3.97	5.11	4.39	0.445
337	27.62124	75.5	75.9	5.81	1.25	1.20	2.00	1.48	0.318
338	27.71799	75.4	75.7	4.21	0.00	0.00	0.00	0.00	0.000
339	27.81353	75.2	75.7	3.45	0.00	0.00	0.00	0.00	0.000
340	27.90986			2.80	0.00	0.00	0.00	0.00	0.000
341	28.23675	75.7	75.3	1.90	0.00	0.00	0.00	0.00	0.000
342	28.43728	75.3	75.9	1.60	0.00	0.00	0.00	0.00	0.000
343	28.83754	75.5	76.0	1.40	0.00	0.00	0.00	0.00	0.000
344	29.61412	75.6	75.4	1.10	0.00	0.00	0.00	0.00	0.000

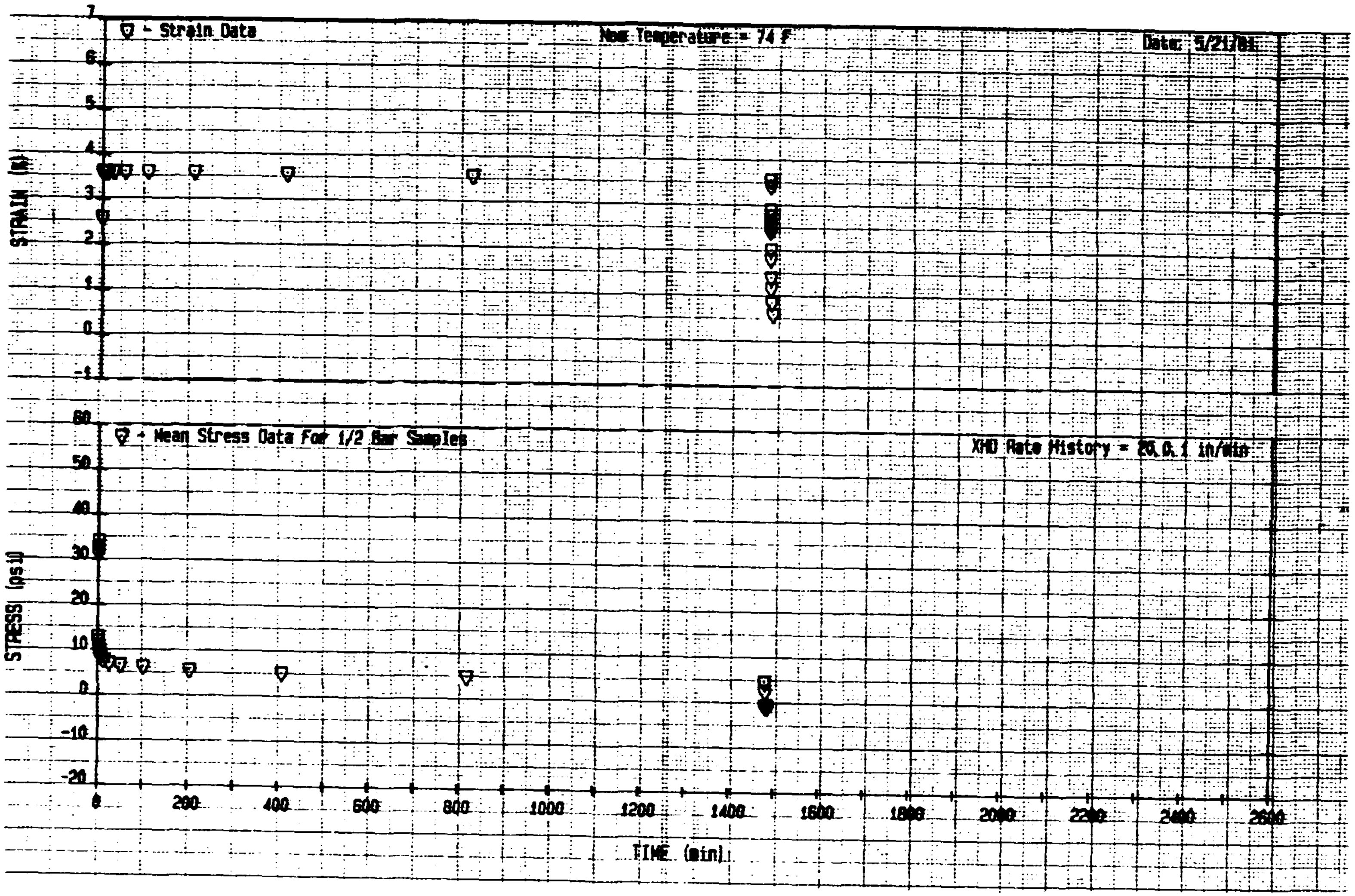

Figure 23. Test No. 8 - Stress While Step Straining for UTP-19,360B-400/1777

28755

TABLE 12. TEST NO. 8 - 1/2-IN. BAR STRESS WHILE STEP STRAINING

PROPELLANT: UTP 19360B 400/1777
REQUESTOR: Carlton
WOR:

DATE: 5/21/81
OPERATOR: JWD

DEFINITIONS:
Time = Time From Start of Test (min)
= Stress (psi)
= Strain (%)
T(air) = Test Air Temperature (F)
T(prop) = Test Propellant Temperature (F)

RELATIONSHIPS:
= Force/Area
= Sample Extension/Length

NOMINAL VALUES:
Test Temp = 74 F
Gage Length = 6.00 in
Nom. Strain = 4 %
XHD Rate = 20.0.1 in/min

CALIBRATION DATA:	SAMPLE 1	SAMPLE 2	SAMPLE 3
Cal Wt = 5.0 lbs			
Load Cal (lbs/volts)	5.850	6.098	6.113
Offset (volts)	0.059	0.022	0.094
Pot Cal (in/volts) =	-0.385		
Temp (F) =	75.1		
CATHATOMETER STRAIN DATA:			
Initial Upper (5 digits)	82925	82705	82710
Initial Lower (5 digits)	68360	68100	68030
Final Upper (5 digits)	82945	82700	82730
Final Lower (5 digits)	67835	67585	67520
Strain at 0.02 min	3.74	3.47	3.61
AREAS (sq in):	0.254	0.253	0.250

STRESS DATA (psi):

SET	Time	T(prop)	T(air)	Strain	SAMPLE 1	SAMPLE 2	SAMPLE 3	Avg	St Dev
1	0.01770			2.60	27.60	31.42	35.60	31.54	2.829
2	0.02100			3.61	35.30	34.10	33.25	34.22	0.728
3	0.02458			3.61	34.00	32.52	32.11	32.88	0.705
4	0.35416	75.9	76.2	3.63	12.72	12.85	13.19	12.92	0.170
5	0.55441	75.9	76.3	3.63	11.79	11.90	12.18	11.96	0.143
6	0.95469	75.5	76.5	3.62	10.78	10.90	11.15	10.94	0.135
7	1.75558	75.6	76.5	3.63	9.86	9.97	10.19	10.00	0.118
8	3.35594	75.4	76.5	3.62	9.00	9.13	9.31	9.15	0.110
9	6.55676	75.8	76.2	3.63	8.33	8.43	8.58	8.44	0.092
10	12.95704	75.8	76.3	3.63	7.66	7.80	7.94	7.80	0.099
11	25.75741	75.4	76.1	3.63	7.13	7.19	7.38	7.23	0.093
12	51.35796	75.6	76.7	3.62	6.72	6.71	6.85	6.76	0.056
13	102.55806	74.9	75.6	3.63	6.36	6.37	6.50	6.41	0.053
14	204.95716	75.4	76.5	3.62	5.70	5.73	5.88	5.77	0.066
15	409.75945	76.1	76.7	3.60	5.17	5.21	5.44	5.27	0.105
16	819.35987	75.5	76.1	3.59	4.84	4.90	5.09	4.94	0.091
17	1478.66933	75.5	76.2	3.58	4.48	4.60	4.78	4.62	0.108
18	1478.97000			3.58	4.48	4.60	4.78	4.62	0.108
19	1478.97676			3.45	2.65	2.46	2.38	2.50	0.101
20	1479.00712			2.92	-0.74	-0.64	-0.63	-0.67	0.045
21	1479.03677			2.79	-0.70	-0.67	-0.63	-0.67	0.027
22	1479.06729			2.69	-0.64	-0.66	-0.63	-0.64	0.009
23	1479.09680			2.60	-0.78	-0.68	-0.64	-0.70	0.053
24	1479.12728			2.52	-0.62	-0.66	-0.63	-0.64	0.015
25	1479.15685			2.44	-0.79	-0.68	-0.65	-0.71	0.053
26	1479.39548			2.04	-0.74	-0.77	-0.65	-0.72	0.045
27	1479.59606	76.1	76.2	1.83	-0.74	-0.68	-0.65	-0.69	0.031
28	1480.31345	76.4	76.1	1.42	-0.77	-0.67	-0.65	-0.70	0.045
29	1481.11404	76.1	76.3	1.10	-0.74	-0.66	-0.65	-0.68	0.034
30	1482.71454	76.0	76.3	0.86	-0.79	-0.67	-0.66	-0.71	0.052
31	1485.91523	75.7	76.2	0.60	-0.77	-0.69	-0.67	-0.71	0.038

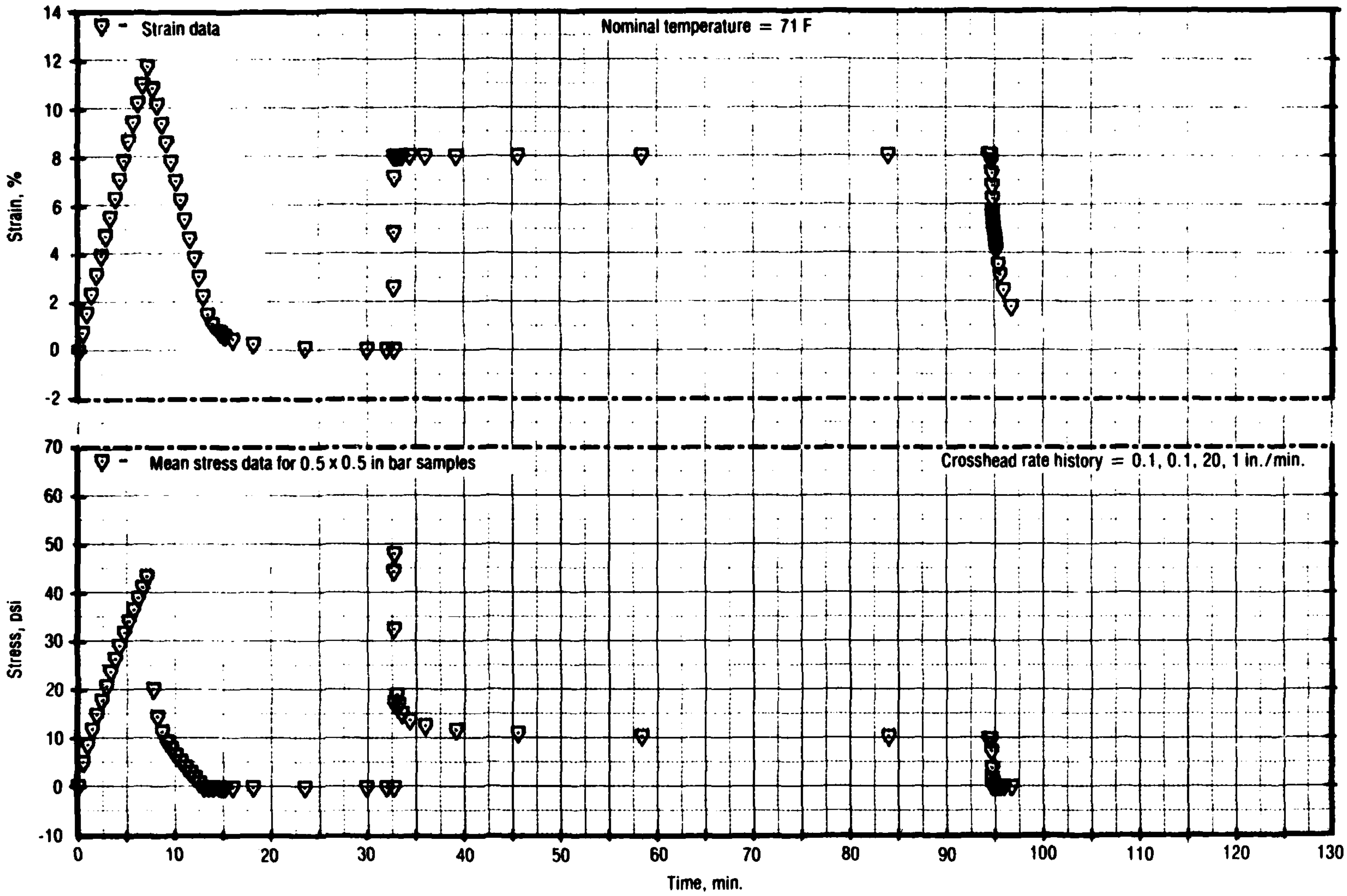

Figure 24. Test No. 9 - Stress While Step Straining for UTP-19,360B-400/1777

28753

TABLE 13. TEST NO. 9 - 1/2-IN. BAR STRESS WHILE STEP STRAINING (SHEET 1 OF 2)

PROPELLANT: UTP 19360B 400/1777
REQUESTOR: CARLTON
WOR:

DATE: 5/28/81
OPERATOR: WRP

DEFINITIONS:
- Time = Time From Start of Test (min)
- σ = Stress (psi)
- ϵ = Strain (%)
- T(air) = Test Air Temperature (F)
- T(prop) = Test Propellant Temperature (F)

RELATIONSHIPS:
- σ = Force/Area
- ϵ = Sample Extension/Length

NOMINAL VALUES:
- Test Temp = 71 F
- Gage Length = 6.00 in
- Nom. Strain = 12,12,8,8 %
- XHD Rate = 0.1,0.1,20,1.0 in/min

CALIBRATION DATA:

	Sample 1	Sample 2	Sample 3
Cal Wt = 5.0 lbs			
Load Cal (lbs/volts)	5.955	7.361	6.165
Offset (volts)	0.085	0.019	0.028
Pot Cal (in/volts) =	-0.388		
Temp (F) =	73.9		

AREAS (sq in): 0.250 0.251 0.252

STRESS DATA (psi):

SET	Time	T(prop)	T(air)	Strain	Sample 1	Sample 2	Sample 3	Avg	St Dev
1	0.00567	75.5	76.4	0.02	0.25	0.24	0.62	0.37	0.154
2	0.48623	75.8	76.4	0.79	5.05	5.45	5.38	5.29	0.149
3	0.96630	75.4	76.0	1.59	8.47	9.15	8.98	8.87	0.250
4	1.44610	75.8	76.0	2.38	11.60	12.21	12.29	12.03	0.266
5	1.92623	76.0	76.1	3.18	14.58	15.06	15.45	15.03	0.307
6	2.40573	75.5	75.9	3.97	17.28	18.18	18.39	17.95	0.418
7	2.88580	75.6	76.1	4.77	19.96	21.45	21.31	20.91	0.584
8	3.36588	75.6	76.1	5.55	22.80	24.64	24.29	23.91	0.690
9	3.84585	75.4	75.7	6.34	25.08	27.68	26.90	26.55	0.947
10	4.32643	75.2	75.6	7.13	27.53	30.67	29.56	29.25	1.127
11	4.80607	75.5	75.6	7.91	30.14	33.55	32.22	31.97	1.214
12	5.28599	75.2	75.3	8.71	32.27	36.35	34.54	34.39	1.446
13	5.76633	75.2	75.5	9.49	34.42	39.02	36.83	36.76	1.627
14	6.24602	75.2	75.1	10.29	36.71	41.61	39.13	39.15	1.731
15	6.72603	75.0	75.2	11.07	38.74	44.09	41.22	41.35	1.891
16	7.20000			11.80	40.90	46.50	43.30	43.57	1.987
17	7.77331	75.1	75.4	10.90	19.43	21.01	20.44	20.29	0.566
18	8.25352	74.8	75.1	10.20	13.96	14.82	15.02	14.60	0.399
19	8.73311	74.7	75.3	9.41	10.95	11.67	11.97	11.53	0.371
20	9.21283	74.7	75.1	8.63	8.83	9.81	9.81	9.48	0.402
21	9.69306	74.5	75.1	7.84	7.37	8.58	8.20	8.05	0.436
22	10.17323	74.7	75.0	7.04	5.80	7.42	6.72	6.65	0.572
23	10.65311	74.6	74.9	6.25	4.73	6.13	5.55	5.47	0.497
24	11.13320	74.4	75.2	5.46	3.62	4.84	4.40	4.29	0.437
25	11.61294	74.5	75.1	4.67	2.56	3.62	3.35	3.18	0.389

TABLE 13. TEST NO. 9 - 1/2-IN. BAR STRESS WHILE STEP STRAINING
(SHEET 2 OF 2)

26	12.09291	74.8	74.7	3.87	1.56	2.43	2.32	2.10	0.336
27	12.57341	75.1	74.9	3.08	0.58	1.22	1.32	1.04	0.286
28	13.05342	75.1	75.2	2.29	0.00	0.05	0.22	0.09	0.082
29	13.53330	74.6	75.0	1.52	0.00	0.00	0.00	0.00	0.000
30	14.01348	74.9	75.1	1.12	0.00	0.00	0.00	0.00	0.000
31	14.62202			0.83	0.00	0.00	0.00	0.00	0.000
32	14.82253	75.0	75.2	0.76	0.00	0.00	0.00	0.00	0.000
33	15.22328	74.3	75.4	0.65	0.00	0.00	0.00	0.00	0.000
34	16.02396	74.3	75.1	0.50	0.00	0.00	0.00	0.00	0.000
35	18.16438	74.5	75.2	0.30	0.00	0.00	0.00	0.00	0.000
36	23.53871	74.7	75.4	0.14	0.00	0.00	0.00	0.00	0.000
37	29.93926	75.0	76.2	0.08	0.00	0.00	0.00	0.00	0.000
38	32.01313	75.3	76.2	0.07	0.00	0.00	0.00	0.00	0.000
39	32.76632			0.07	0.00	0.00	0.00	0.00	0.000
40	32.77321			2.63	14.68	17.55	20.02	17.42	1.889
41	32.78008			4.90	29.33	35.11	33.46	32.64	2.108
42	32.78697			7.17	40.78	47.74	45.11	44.54	2.485
43	32.79385			8.04	44.60	51.30	48.70	48.20	2.389
44	33.01230	75.3	76.1	8.04	18.35	19.29	19.48	19.04	0.427
45	33.21297	75.2	76.0	8.04	16.40	17.00	17.57	16.99	0.411
46	33.61374	75.4	76.2	8.05	14.52	15.06	15.80	15.13	0.453
47	34.41451	75.4	75.9	8.05	13.36	13.50	14.46	13.77	0.423
48	36.01507	75.2	75.7	8.05	12.25	12.32	13.32	12.63	0.422
49	39.21532	75.5	75.6	8.05	11.40	11.46	12.44	11.77	0.414
50	45.61603	74.4	75.2	8.05	10.71	10.76	11.72	11.06	0.402
51	58.41664	75.4	76.1	8.05	10.04	10.17	11.06	10.42	0.391
52	84.01719	75.0	76.2	8.06	9.53	10.82	10.46	10.27	0.473
53	94.36739	75.6	76.6	8.06	9.13	9.89	10.16	9.73	0.379
54	94.61500			8.06	9.12	9.86	10.16	9.71	0.378
55	94.64826	75.5	77.0	7.82	6.77	7.54	7.22	7.17	0.273
56	94.68067	75.8	76.5	7.29	2.99	4.29	3.69	3.66	0.460
57	94.71270	75.7	76.7	6.76	1.14	1.99	1.69	1.61	0.304
58	94.74468	75.4	76.8	6.23	0.00	0.26	0.23	0.16	0.101
59	94.77676	75.5	76.8	5.70	0.00	0.00	0.00	0.00	0.000
60	94.80883	75.5	76.4	5.52	0.00	0.00	0.00	0.00	0.000
61	94.84033	76.1	77.0	5.35	0.00	0.00	0.00	0.00	0.000
62	94.87229	76.1	76.8	5.19	0.00	0.00	0.00	0.00	0.000
63	94.90441	76.5	76.7	5.04	0.00	0.00	0.00	0.00	0.000
64	94.93653	75.8	76.6	4.89	0.00	0.00	0.00	0.00	0.000
65	94.96867	75.6	77.1	4.76	0.00	0.00	0.00	0.00	0.000
66	95.00078	75.8	76.8	4.62	0.00	0.00	0.00	0.00	0.000
67	95.03293	75.7	76.3	4.50	0.00	0.00	0.00	0.00	0.000
68	95.06425	75.7	77.0	4.38	0.00	0.00	0.00	0.00	0.000
69	95.09641	76.2	76.8	4.27	0.00	0.00	0.00	0.00	0.000
70	95.12857			4.16	0.00	0.00	0.00	0.00	0.000
71	95.35603	75.6	76.8	3.52	0.00	0.00	0.00	0.00	0.000
72	95.55649	76.8	76.5	3.09	0.00	0.00	0.00	0.00	0.000
73	95.95743	76.1	76.8	2.47	0.00	0.00	0.00	0.00	0.000
74	96.75788	75.9	76.1	1.78	0.00	0.00	0.00	0.00	0.000

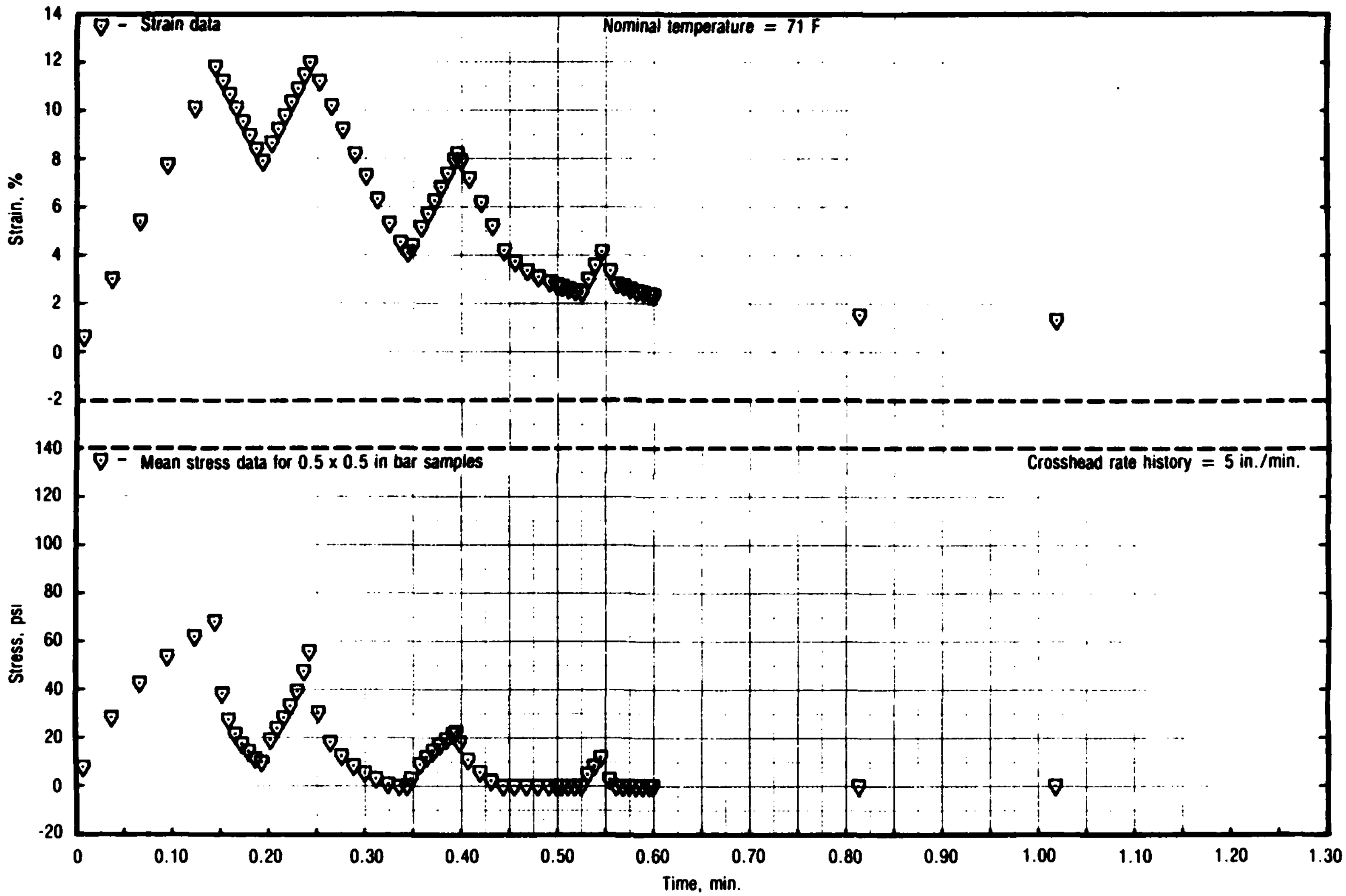

Figure 25. Test No. 10 - Stress While Complex Straining for UTP-19,360B-400/1777

28799

TABLE 14. TEST NO. 10 - 1/2-IN. BAR STRESS WHILE COMPLEX STRAINING (SHEET 1 OF 2)

PROPELLANT: UTP 19360B 400/1777
REQUESTOR: Carlton
WOR:

DATE: 5/15/81
OPERATOR: JWD

DEFINITIONS:
- Time = Time From Start of Test (min)
- σ = Stress (psi)
- ε = Strain (%)
- T(air) = Test Air Temperature (F)
- T(prop) = Test Propellant Temperature (F)

RELATIONSHIPS:
- σ = Force/Area
- ε = Sample Extension/Length

NOMINAL VALUES:
- Test Temp = 71 F
- Gage Length = 6.00 in
- Nom. Strain = 12,8,12,4,8,0,4,0 %
- XHD Rate = 5 in/min

CALIBRATION DATA:

		Sample 1	Sample 2	Sample 3
Cal Wt = 5.0 lbs				
Load Cal	(lbs/volts)	5.855	6.078	6.119
Offset	(volts)	0.038	0.013	0.092
Pot Cal	(in/volts) =	-0.386		
Temp	(F) =	73.1		

AREAS (sq in): 0.252 0.251 0.249

STRESS DATA (psi):

SET	Time	T(prop)	T(air)	Strain	Sample 1	Sample 2	Sample 3	Avg	St Dev
1	0.00744			0.61	6.40	7.88	8.78	7.69	0.848
2	0.03682			3.02	26.82	29.39	29.07	28.43	0.991
3	0.06548			5.41	40.83	44.24	42.70	42.59	1.207
4	0.09408			7.75	51.99	55.74	53.18	53.64	1.354
5	0.12268			10.11	60.73	64.23	60.95	61.97	1.384
6	0.14379			11.81	67.22	70.56	66.84	68.21	1.447
7	0.15167			11.22	40.40	39.50	35.04	38.31	2.031
8	0.15857			10.66	28.65	28.32	25.26	27.41	1.319
9	0.16544			10.11	22.35	22.26	19.85	21.49	1.001
10	0.17232			9.54	18.12	18.13	16.09	17.44	0.832
11	0.17920			8.97	15.00	15.03	13.24	14.42	0.725
12	0.18607			8.41	11.89	11.94	10.40	11.41	0.618
13	0.19271			7.90	10.39	10.39	8.93	9.90	0.595
14	0.20203			8.66	18.64	19.84	18.99	19.16	0.437
15	0.20889			9.23	23.48	24.65	23.50	23.88	0.472
16	0.21578			9.79	27.93	29.22	27.85	28.33	0.545
17	0.22264			10.35	32.59	34.26	32.75	33.20	0.653
18	0.22949			10.91	38.43	40.55	38.87	39.28	0.791
19	0.23636			11.48	46.34	49.03	47.19	47.52	0.973
20	0.24210			11.98	54.24	57.50	55.50	55.75	1.164
21	0.25194			11.21	32.04	31.40	27.68	30.37	1.667
22	0.26437			10.19	18.98	18.88	16.65	18.17	0.931
23	0.27601			9.24	13.10	13.12	11.40	12.54	0.696
24	0.28853			8.20	8.95	8.94	7.52	8.47	0.582
25	0.30015			7.30	5.90	5.90	4.72	5.51	0.483
26	0.31185			6.32	3.54	3.44	2.41	3.13	0.444
27	0.32419			5.31	1.15	1.10	0.27	0.84	0.347

TABLE 14. TEST NO. 10 - 1/2-IN. BAR STRESS WHILE COMPLEX STRAINING
(SHEET 2 OF 2)

28	0.33589			4.53	0.00	0.00	0.00	0.00	0.000
29	0.34400			4.10	0.00	0.00	0.00	0.00	0.000
30	0.34823			4.40	2.34	3.69	3.09	3.04	0.478
31	0.35749			5.16	8.78	9.48	8.84	9.03	0.274
32	0.36434			5.71	11.88	12.54	11.78	12.07	0.290
33	0.37119			6.26	14.39	15.18	14.30	14.62	0.343
34	0.37804			6.82	16.90	17.64	16.63	17.06	0.368
35	0.38488			7.38	19.20	19.98	18.89	19.36	0.400
36	0.39173			7.95	21.35	22.31	21.09	21.58	0.452
37	0.39500			8.22	22.18	23.24	21.95	22.46	0.487
38	0.39859			7.91	19.48	18.65	16.08	18.07	1.253
39	0.40729			7.18	11.51	11.33	9.69	10.85	0.710
40	0.41969			6.18	6.24	6.03	4.79	5.68	0.555
41	0.43129			5.22	2.63	2.44	1.47	2.18	0.441
42	0.44379			4.19	0.00	0.00	0.00	0.00	0.000
43	0.45542			3.73	0.00	0.00	0.00	0.00	0.000
44	0.46791			3.36	0.00	0.00	0.00	0.00	0.000
45	0.47950			3.10	0.00	0.00	0.00	0.00	0.000
46	0.49123			2.89	0.00	0.00	0.00	0.00	0.000
47	0.49899			2.77	0.00	0.00	0.00	0.00	0.000
48	0.50413			2.70	0.00	0.00	0.00	0.00	0.000
49	0.51097			2.61	0.00	0.00	0.00	0.00	0.000
50	0.51782			2.53	0.00	0.00	0.00	0.00	0.000
51	0.52469			2.46	0.00	0.00	0.00	0.00	0.000
52	0.53151			3.00	4.64	5.36	4.71	4.90	0.281
53	0.53833			3.59	8.13	8.87	8.21	8.40	0.286
54	0.54516			4.15	11.63	12.38	11.71	11.91	0.291
55	0.55430			3.35	3.41	2.95	1.78	2.71	0.596
56	0.56113			2.80	0.00	0.00	0.00	0.00	0.000
57	0.56796			2.73	0.00	0.00	0.00	0.00	0.000
58	0.57480			2.60	0.00	0.00	0.00	0.00	0.000
59	0.58164			2.50	0.00	0.00	0.00	0.00	0.000
60	0.58849			2.46	0.00	0.00	0.00	0.00	0.000
61	0.59534			2.39	0.00	0.00	0.00	0.00	0.000
62	0.59932			2.34	0.00	0.00	0.00	0.00	0.000
63	0.81334	74.3	74.1	1.50	0.00	0.00	0.00	0.00	0.000
64	1.01771	74.3	74.5	1.30	0.00	0.00	0.00	0.00	0.000

TABLE 15. TEST NO. 11, PART 1 - QUINLAN COMPLEX HISTORY FOR UTP-3001

T7859

Cycle		Rate, in./min.	Remarks
1-7	Load	2	Approximately 15 min. rest after cycle
	Unload	2	Approximately 15 min. rest after cycle
8	Load	1	Approximately 15 min. rest after cycle
	Unload	1	
9	Load	5	Approximately 15 min. rest after cycle
	Unload	5	
10	Load	0.5	Approximately 15 min. rest after cycle
	Unload	0.5	
11	Load	10	Approximately 15 min. rest after cycle
	Unload	10	
12	Load	0.2	Approximately 15 min. rest after cycle
	Unload	0.2	
13	Load	2	
	Relax	1/2 hr	
	Unload	2	Approximately 30 min. rest after cycle
14	Load	2	
	Relax	1 hr	
	Unload	2	4 day rest after cycle
15	Load	2	
	Relax	1 hr	
	Unload	2	7 day rest after cycle

The later part of the cycling is represented only by the maximum and minimum stress-strain points. Part 3 of this test, the balance of cycling to failure, is recorded in Table 19 as maxima and minima for selected cycles sufficiently close to describe the upper and lower bounds. A plot of the data would be similar to Figure 32. The strain values in Table 19 are stable, while the maximum stress shows a continual decay, and compressive (negative values) stresses become less compressive.

(Text continued on page 76)

TABLE 16. TEST NO. 11, PART 1 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 1 OF 11)

PROPELLANT: UTP 3001 750/7768
REQUESTOR: Carlton
WOR:

DATE: 1/4/82
OPERATOR: JWD

DEFINITIONS:
Time = Time From Start of Test (min)
σ = Stress (psi)
ϵ = Strain (%)
T(air) = Test Air Temperature (F)
T(prop) = Test Propellant Temperature (F)

RELATIONSHIPS:
σ = Force/Area
ϵ = Sample Extension/Length

NOMINAL VALUES:
Test Temp = 70 F
Gage Length = 6.00 in
Nom. Strain = 3,6,8 %
XHD Rate = 2 in/min

CALIBRATION DATA:

		SAMPLE 1
Cal Wt = 5.0 lbs		
Load Cal	(lbs/in)	5.000
Offset	(in)	0.000
Temp	(F) =	70.0

AREAS (sq in): 0.251

STRESS DATA (psi):

SET	Time	T(prop)	T(air)	Strain	SAMPLE 1	Avg	St Dev
1	0.00500			0.17	3.43	3.43	0.000
2	0.01000			0.33	6.29	6.29	0.000
3	0.01500	0.0	0.0	0.50	9.32	9.32	0.000
4	0.02000			0.67	11.87	11.87	0.000
5	0.02500			0.83	14.34	14.34	0.000
6	0.03000			1.00	16.57	16.57	0.000
7	0.03500			1.17	18.96	18.96	0.000
8	0.05000			1.67	25.34	25.34	0.000
9	0.06500			2.17	31.39	31.39	0.000
10	0.08000			2.67	37.21	37.21	0.000
11	0.09250			3.08	41.83	41.83	0.000
12	0.09350			3.05	37.45	37.45	0.000
13	0.09500			3.00	33.86	33.86	0.000
14	0.09750			2.92	27.89	27.89	0.000
15	0.10000			2.83	23.11	23.11	0.000
16	0.10500			2.67	17.05	17.05	0.000
17	0.11000			2.50	12.91	12.91	0.000
18	0.11500			2.33	9.96	9.96	0.000
19	0.12000			2.17	7.81	7.81	0.000
20	0.12500			2.00	5.82	5.82	0.000
21	0.13500			1.67	3.03	3.03	0.000
22	0.14500			1.33	0.64	0.64	0.000
23	0.16000			0.83	-2.47	-2.47	0.000

TABLE 16. TEST NO. 11, PART 1 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 2 OF 11)

24	0.18000	0.17	-7.17	-7.17	0.000
25	0.20000	0.17	-4.30	-4.30	0.000
26	0.22000	0.17	-3.19	-3.19	0.000
27	0.24000	0.17	-2.55	-2.55	0.000
28	0.26000	0.17	-2.07	-2.07	0.000
29	0.28000	0.17	-1.59	-1.59	0.000
30	0.32000	0.17	-1.35	-1.35	0.000
31	0.38000	0.17	-1.20	-1.20	0.000
32	0.48000	0.17	-0.88	-0.88	0.000
33	0.58000	0.17	-0.72	-0.72	0.000
34	0.98000	0.17	-0.56	-0.56	0.000
35	2.98000	0.17	-0.40	-0.40	0.000
36	6.98000	0.17	-0.32	-0.32	0.000
37	12.98000	0.17	-0.32	-0.32	0.000
38	15.38000	0.17	-0.32	-0.32	0.000
39	15.38500	0.33	2.55	2.55	0.000
40	15.39000	0.50	5.26	5.26	0.000
41	15.39500	0.67	7.57	7.57	0.000
42	15.40500	1.00	11.63	11.63	0.000
43	15.41500	1.33	15.22	15.22	0.000
44	15.42500	1.67	18.49	18.49	0.000
45	15.44000	2.17	23.51	23.51	0.000
46	15.45000	2.50	27.41	27.41	0.000
47	15.46000	2.83	31.87	31.87	0.000
48	15.47000	3.17	37.29	37.29	0.000
49	15.48000	3.50	42.87	42.87	0.000
50	15.49000	3.83	47.41	47.41	0.000
51	15.50200	4.23	52.11	52.11	0.000
52	15.50400	4.17	46.77	46.77	0.000
53	15.50600	4.10	41.51	41.51	0.000
54	15.50800	4.03	35.30	35.30	0.000
55	15.51100	3.93	29.72	29.72	0.000
56	15.51600	3.77	22.71	22.71	0.000
57	15.52100	3.60	18.01	18.01	0.000
58	15.52600	3.43	14.74	14.74	0.000
59	15.53100	3.27	12.11	12.11	0.000
60	15.54100	2.93	8.53	8.53	0.000
61	15.55100	2.60	5.66	5.66	0.000
62	15.56600	2.10	2.31	2.31	0.000
63	15.58100	1.60	-0.56	-0.56	0.000
64	15.59600	1.10	-3.11	-3.11	0.000
65	15.60600	0.77	-4.78	-4.78	0.000
66	15.62000	0.30	-7.89	-7.89	0.000
67	15.64000	0.30	-4.78	-4.78	0.000
68	15.66000	0.30	-3.67	-3.67	0.000
69	15.68000	0.30	-2.87	-2.87	0.000
70	15.70000	0.30	-2.31	-2.31	0.000
71	15.74000	0.30	-1.83	-1.83	0.000
72	15.78000	0.30	-1.59	-1.59	0.000
73	15.84000	0.30	-1.27	-1.27	0.000
74	15.94000	0.30	-1.12	-1.12	0.000
75	16.04000	0.30	-0.96	-0.96	0.000

TABLE 16. TEST NO. 11, PART 1 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 3 OF 11)

76	16.24000	0.30	-0.72	-0.72	0.000
77	16.84000	0.30	-0.56	-0.56	0.000
78	19.64000	0.30	-0.40	-0.40	0.000
79	23.64000	0.30	-0.32	-0.32	0.000
80	29.84000	0.30	-0.32	-0.32	0.000
81	29.84500	0.47	2.79	2.79	0.000
82	29.85000	0.63	5.34	5.34	0.000
83	29.85500	0.80	7.41	7.41	0.000
84	29.86500	1.13	11.08	11.08	0.000
85	29.88000	1.63	15.94	15.94	0.000
86	29.89500	2.13	20.16	20.16	0.000
87	29.91000	2.63	24.70	24.70	0.000
88	29.92500	3.13	29.64	29.64	0.000
89	29.94000	3.63	35.86	35.86	0.000
90	29.95500	4.13	44.06	44.06	0.000
91	29.96500	4.47	50.44	50.44	0.000
92	29.97500	4.80	55.62	55.62	0.000
93	29.98500	5.13	59.76	59.76	0.000
94	29.99100	5.33	61.83	61.83	0.000
95	29.99300	5.27	54.66	54.66	0.000
96	29.99500	5.20	47.57	47.57	0.000
97	29.99800	5.10	40.32	40.32	0.000
98	30.00000	5.03	35.06	35.06	0.000
99	30.00250	4.95	30.52	30.52	0.000
100	30.00500	4.87	27.81	27.81	0.000
101	30.01000	4.70	22.71	22.71	0.000
102	30.02000	4.37	16.25	16.25	0.000
103	30.03000	4.03	12.19	12.19	0.000
104	30.04500	3.53	7.81	7.81	0.000
105	30.06500	2.87	3.67	3.67	0.000
106	30.08500	2.20	0.16	0.16	0.000
107	30.10500	1.53	-2.63	-2.63	0.000
108	30.12000	1.03	-4.86	-4.86	0.000
109	30.86000	1.03	-8.13	-8.13	0.000
110	30.88000	1.03	-5.02	-5.02	0.000
111	30.90000	1.03	-3.82	-3.82	0.000
112	30.92000	1.03	-3.03	-3.03	0.000
113	30.98000	1.03	-2.07	-2.07	0.000
114	31.02000	1.03	-1.67	-1.67	0.000
115	31.06000	1.03	-1.51	-1.51	0.000
116	31.12000	1.03	-1.43	-1.43	0.000
117	31.22000	1.03	-1.20	-1.20	0.000
118	31.32000	1.03	-1.04	-1.04	0.000
119	31.72000	1.03	-0.72	-0.72	0.000
120	32.72000	1.03	-0.56	-0.56	0.000
121	34.72000	1.03	-0.40	-0.40	0.000
122	38.72000	1.03	-0.32	-0.32	0.000
123	46.96000	1.03	-0.32	-0.32	0.000
124	46.96400	1.17	1.79	1.79	0.000
125	46.96900	1.33	4.58	4.58	0.000
126	46.97400	1.50	6.57	6.57	0.000
127	46.98400	1.83	10.16	10.16	0.000
128	46.99400	2.17	13.35	13.35	0.000
129	47.00400	2.50	15.94	15.94	0.000

TABLE 16. TEST NO. 11, PART 1 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 4 OF 11)

130	47.02400	3.17	21.31	21.31	0.000
131	47.04400	3.83	26.49	26.49	0.000
132	47.06400	4.50	32.47	32.47	0.000
133	47.08400	5.17	40.24	40.24	0.000
134	47.10400	5.83	51.59	51.59	0.000
135	47.12400	6.50	64.14	64.14	0.000
136	47.14050	7.05	72.11	72.11	0.000
137	47.14250	6.98	66.33	66.33	0.000
138	47.14400	6.93	60.76	60.76	0.000
139	47.14650	6.85	52.99	52.99	0.000
140	47.14900	6.77	45.42	45.42	0.000
141	47.15400	6.60	35.86	35.86	0.000
142	47.15900	6.43	29.28	29.28	0.000
143	47.16650	6.18	22.71	22.71	0.000
144	47.17400	5.93	18.53	18.53	0.000
145	47.18400	5.60	14.34	14.34	0.000
146	47.19900	5.10	10.36	10.36	0.000
147	47.21900	4.43	5.98	5.98	0.000
148	47.23900	3.77	2.39	2.39	0.000
149	47.26400	2.93	-1.00	-1.00	0.000
150	47.28900	2.10	-3.98	-3.98	0.000
151	47.31950	1.08	-8.37	-8.37	0.000
152	47.33950	1.08	-5.78	-5.78	0.000
153	47.35950	1.08	-4.38	-4.38	0.000
154	47.39950	1.08	-2.79	-2.79	0.000
155	47.43950	1.08	-2.19	-2.19	0.000
156	47.49950	1.08	-1.79	-1.79	0.000
157	47.59950	1.08	-1.59	-1.59	0.000
158	47.69950	1.08	-1.39	-1.39	0.000
159	47.89950	1.08	-1.00	-1.00	0.000
160	48.09950	1.08	-0.80	-0.80	0.000
161	48.69950	1.08	-0.60	-0.60	0.000
162	52.69950	1.08	-0.40	-0.40	0.000
163	60.77950	1.08	-0.40	-0.40	0.000
164	60.78750	1.35	4.18	4.18	0.000
165	60.79250	1.52	6.37	6.37	0.000
166	60.79750	1.68	8.17	8.17	0.000
167	60.80750	2.02	11.16	11.16	0.000
168	60.82250	2.52	15.14	15.14	0.000
169	60.84250	3.18	19.72	19.72	0.000
170	60.86250	3.85	24.50	24.50	0.000
171	60.88750	4.68	30.88	30.88	0.000
172	60.91250	5.52	38.65	38.65	0.000
173	60.93750	6.35	50.20	50.20	0.000
174	60.96250	7.18	66.14	66.14	0.000
175	60.98950	8.08	78.49	78.49	0.000
176	60.99250	7.98	66.73	66.73	0.000
177	60.99500	7.90	57.77	57.77	0.000
178	60.99750	7.82	50.80	50.80	0.000
179	61.00250	7.65	40.64	40.64	0.000
180	61.00750	7.48	33.86	33.86	0.000
181	61.01250	7.32	28.69	28.69	0.000
182	61.02250	6.98	22.11	22.11	0.000
183	61.03250	6.65	17.73	17.73	0.000

TABLE 16. TEST NO. 11, PAFT 1 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 5 OF 11)

184	61.04250	6.32	14.34	14.34	0.000
185	61.05750	5.82	10.56	10.56	0.000
186	61.07750	5.15	6.97	6.97	0.000
187	61.10250	4.32	2.79	2.79	0.000
188	61.12750	3.48	-0.20	-0.20	0.000
189	61.15250	2.65	-3.19	-3.19	0.000
190	61.17750	1.82	-5.78	-5.78	0.000
191	61.19700	1.17	-8.57	-8.57	0.000
192	61.21700	1.17	-5.98	-5.98	0.000
193	61.23700	1.17	-4.78	-4.78	0.000
194	61.25700	1.17	-3.98	-3.98	0.000
195	61.31700	1.17	-2.39	-2.39	0.000
196	61.41700	1.17	-1.99	-1.99	0.000
197	61.61700	1.17	-1.39	-1.39	0.000
198	62.01700	1.17	-1.00	-1.00	0.000
199	62.41700	1.17	-0.80	-0.80	0.000
200	66.41700	1.17	-0.60	-0.60	0.000
201	75.55700	1.17	-0.40	-0.40	0.000
202	75.56350	1.38	3.19	3.19	0.000
203	75.56850	1.55	5.58	5.58	0.000
204	75.57350	1.72	7.37	7.37	0.000
205	75.57850	1.88	8.96	8.96	0.000
206	75.58850	2.22	11.75	11.75	0.000
207	75.61350	3.05	17.53	17.53	0.000
208	75.64350	4.05	23.90	23.90	0.000
209	75.67850	5.22	31.87	31.87	0.000
210	75.71350	6.38	42.23	42.23	0.000
211	75.74350	7.38	56.18	56.18	0.000
212	75.76850	8.22	74.30	74.30	0.000
213	75.77350	8.05	59.16	59.16	0.000
214	75.77850	7.88	45.82	45.82	0.000
215	75.78350	7.72	37.25	37.25	0.000
216	75.79350	7.38	26.89	26.89	0.000
217	75.80350	7.05	21.12	21.12	0.000
218	75.81350	6.72	16.93	16.93	0.000
219	75.82500	6.33	12.55	12.55	0.000
220	75.84850	5.55	8.37	8.37	0.000
221	75.87350	4.72	4.38	4.38	0.000
222	75.89350	4.05	1.00	1.00	0.000
223	75.92350	3.05	-1.99	-1.99	0.000
224	75.94850	2.22	-4.78	-4.78	0.000
225	77.14850	2.22	-8.37	-8.37	0.000
226	77.16850	2.22	-5.78	-5.78	0.000
227	77.19250	2.22	-3.98	-3.98	0.000
228	77.20850	2.22	-2.99	-2.99	0.000
229	77.24850	2.22	-2.59	-2.59	0.000
230	77.44850	2.22	-1.99	-1.99	0.000
231	77.54850	2.22	-1.59	-1.59	0.000
232	77.94850	2.22	-1.20	-1.20	0.000
233	85.14850	2.22	-0.60	-0.60	0.000
234	92.22850	2.22	-0.60	-0.60	0.000
235	92.23650	2.48	3.59	3.59	0.000
236	92.24150	2.65	5.78	5.78	0.000
237	92.24650	2.82	7.57	7.57	0.000

TABLE 16. TEST NO. 11, PART 1 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 6 OF 11)

238	92.25150	2.98	8.96	8.96	0.000
239	92.27650	3.82	15.14	15.14	0.000
240	92.30150	4.65	20.52	20.52	0.000
241	92.32650	5.48	25.50	25.50	0.000
242	92.35150	6.32	31.08	31.08	0.000
243	92.37650	7.15	37.25	37.25	0.000
244	92.40150	7.98	46.21	46.21	0.000
245	92.42150	8.65	56.37	56.37	0.000
246	92.43900	8.07	68.33	68.33	0.000
247	92.44150	7.98	60.76	60.76	0.000
248	92.44650	7.82	47.81	47.81	0.000
249	92.45150	7.65	38.84	38.84	0.000
250	92.45650	7.48	32.27	32.27	0.000
251	92.46650	7.15	24.30	24.30	0.000
252	92.48650	6.48	15.54	15.54	0.000
253	92.50900	5.73	10.16	10.16	0.000
254	92.53650	4.82	5.18	5.18	0.000
255	92.56150	3.98	1.79	1.79	0.000
256	92.59650	2.82	-1.79	-1.79	0.000
257	92.61400	2.23	-4.18	-4.18	0.000
258	92.64700	1.13	-8.37	-8.37	0.000
260	92.66700	1.13	-5.98	-5.98	0.000
261	92.68700	1.13	-4.38	-4.38	0.000
262	92.70700	1.13	-3.39	-3.39	0.000
263	92.72700	1.13	-2.99	-2.99	0.000
264	92.76700	1.13	-2.59	-2.59	0.000
265	92.82700	1.13	-2.19	-2.19	0.000
266	93.02700	1.13	-1.59	-1.59	0.000
267	93.62700	1.13	-1.00	-1.00	0.000
268	94.82700	1.13	-0.80	-0.80	0.000
269	98.82700	1.13	-0.60	-0.60	0.000
270	108.02700	1.13	-0.60	-0.60	0.000
271	108.03700	1.30	1.79	1.79	0.000
272	108.04700	1.47	3.78	3.78	0.000
273	108.06700	1.80	6.57	6.57	0.000
274	108.08700	2.13	8.76	8.76	0.000
275	108.12700	2.80	12.35	12.35	0.000
276	108.16700	3.47	15.94	15.94	0.000
277	108.18700	3.80	17.53	17.53	0.000
278	108.23700	4.63	21.71	21.71	0.000
279	108.28700	5.47	26.49	26.49	0.000
280	108.33700	6.30	31.87	31.87	0.000
281	108.38200	7.05	38.84	38.84	0.000
282	108.41700	7.63	46.61	46.61	0.000
283	108.45200	8.22	58.17	58.17	0.000
284	108.45700	8.13	49.40	49.40	0.000
285	108.46700	7.97	38.65	38.65	0.000
286	108.48200	7.72	28.88	28.88	0.000
287	108.50700	7.30	20.92	20.92	0.000
288	108.53700	6.80	15.54	15.54	0.000
289	108.56700	6.30	1.99	1.99	0.000
290	108.60200	5.72	8.57	8.57	0.000
291	108.63700	5.13	6.18	6.18	0.000
292	108.69700	4.13	2.39	2.39	0.000

TABLE 16. TEST NO. 11, PART 1 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 7 OF 11)

293	108.75700	3.13	-0.60	-0.60	0.000
294	108.81200	2.22	-3.59	-3.59	0.000
295	108.86900	1.27	-6.57	-6.57	0.000
296	108.88900	1.27	-5.38	-5.38	0.000
297	108.90900	1.27	-4.38	-4.38	0.000
298	108.92900	1.27	-3.78	-3.78	0.000
299	108.96900	1.27	-2.99	-2.99	0.000
300	109.02900	1.27	-2.59	-2.59	0.000
301	109.12900	1.27	-1.99	-1.99	0.000
302	109.42900	1.27	-1.39	-1.39	0.000
303	109.82900	1.27	-1.00	-1.00	0.000
304	110.82900	1.27	-0.80	-0.80	0.000
305	114.82900	1.27	-0.60	-0.60	0.000
306	123.18900	1.27	-0.40	-0.40	0.000
307	123.19340	1.63	4.98	4.98	0.000
308	123.19740	1.97	9.56	9.56	0.000
309	123.20140	2.30	12.95	12.95	0.000
310	123.20540	2.63	16.14	16.14	0.000
311	123.20940	2.97	19.12	19.12	0.000
312	123.22040	3.88	25.10	25.10	0.000
313	123.22740	4.47	30.68	30.68	0.000
314	123.23840	5.38	37.85	37.85	0.000
315	123.24840	6.22	45.02	45.02	0.000
316	123.25840	7.05	54.18	54.18	0.000
317	123.26640	7.72	64.74	64.74	0.000
318	123.27040	8.05	70.92	70.92	0.000
319	123.27460	8.40	78.09	78.09	0.000
320	123.27540	8.33	73.70	73.70	0.000
321	123.27740	8.17	62.15	62.15	0.000
322	123.27940	8.00	51.79	51.79	0.000
323	123.28140	7.83	43.82	43.82	0.000
324	123.28540	7.50	32.27	32.27	0.000
325	123.28940	7.17	24.50	24.50	0.000
326	123.29840	6.42	14.74	14.74	0.000
327	123.31140	5.33	6.57	6.57	0.000
328	123.32540	4.17	0.80	0.80	0.000
329	123.34140	2.83	-4.38	-4.38	0.000
330	123.35740	1.50	-9.56	-9.56	0.000
331	123.37740	1.50	-6.57	-6.57	0.000
332	123.39740	1.50	-4.78	-4.78	0.000
333	123.41740	1.50	-3.39	-3.39	0.000
334	123.45740	1.50	-1.79	-1.79	0.000
335	123.55740	1.50	-1.39	-1.39	0.000
336	123.65740	1.50	-1.00	-1.00	0.000
337	123.95740	1.50	-0.60	-0.60	0.000
338	130.15740	1.50	-0.40	-0.40	0.000
339	137.45740	1.50	-0.40	-0.40	0.000
340	137.48740	1.75	2.59	2.59	0.000
341	137.52740	2.08	4.78	4.78	0.000
342	137.59740	2.67	8.37	8.37	0.000
343	137.67740	3.33	11.16	11.16	0.000
344	137.77740	4.17	14.74	14.74	0.000
345	137.85740	4.83	17.33	17.33	0.000
346	137.95740	5.67	21.12	21.12	0.000

TABLE 16. TEST NO. 11, PART 1 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 8 OF 11)

347	138.05740	6.50	25.10	25.10	0.000
348	138.14740	7.25	30.28	30.28	0.000
349	138.21740	7.83	36.06	36.06	0.000
350	138.29340	8.47	46.02	46.02	0.000
351	138.30740	8.35	36.45	36.45	0.000
352	138.32740	8.18	29.28	29.28	0.000
353	138.35740	7.93	23.31	23.31	0.000
354	138.38740	7.68	19.92	19.92	0.000
355	138.44740	7.18	14.94	14.94	0.000
356	138.54740	6.35	9.96	9.96	0.000
357	138.66740	5.35	5.98	5.98	0.000
358	138.74740	4.68	3.59	3.59	0.000
359	138.85740	3.77	1.00	1.00	0.000
360	138.95740	2.93	-1.39	-1.39	0.000
361	139.12740	1.52	-5.18	-5.18	0.000
362	139.16740	1.52	-3.98	-3.98	0.000
363	139.20740	1.52	-2.99	-2.99	0.000
364	139.24740	1.52	-2.79	-2.79	0.000
365	139.32740	1.52	-2.39	-2.39	0.000
366	139.52740	1.52	-1.79	-1.79	0.000
367	139.92740	1.52	-1.39	-1.39	0.000
368	140.52740	1.52	-1.00	-1.00	0.000
369	141.12740	1.52	-0.80	-0.80	0.000
370	147.12740	1.52	-0.60	-0.60	0.000
371	152.94740	1.52	-0.60	-0.60	0.000
372	152.94930	1.83	5.18	5.18	0.000
373	152.95130	2.17	10.56	10.56	0.000
374	152.95480	2.75	17.53	17.53	0.000
375	152.95980	3.58	26.49	26.49	0.000
376	152.96430	4.33	33.47	33.47	0.000
377	152.97030	5.33	42.23	42.23	0.000
378	152.97510	6.13	49.40	49.40	0.000
379	152.97930	6.83	57.77	57.77	0.000
380	152.98230	7.33	63.15	63.15	0.000
381	152.98480	7.75	69.92	69.92	0.000
382	152.98830	8.33	82.07	82.07	0.000
383	152.99130	8.83	94.02	94.02	0.000
384	152.99420	9.32	104.18	104.18	0.000
385	152.99480	9.22	97.01	97.01	0.000
386	152.99580	9.05	87.65	87.65	0.000
387	152.99630	8.97	81.08	81.08	0.000
388	152.99730	8.80	69.92	69.92	0.000
389	152.99830	8.63	60.16	60.16	0.000
390	152.99980	8.38	48.80	48.80	0.000
391	153.00130	8.13	40.04	40.04	0.000
392	153.00330	7.80	31.27	31.27	0.000
393	153.00630	7.30	22.11	22.11	0.000
394	153.01130	6.47	12.35	12.35	0.000
395	153.01580	5.72	6.57	6.57	0.000
396	153.02080	4.88	1.79	1.79	0.000
397	153.02580	4.05	-1.99	-1.99	0.000
398	153.03080	3.22	-5.38	-5.38	0.000
399	153.03890	1.87	-11.16	-11.16	0.000
400	153.05890	1.87	-5.98	-5.98	0.000

TABLE 16. TEST NO. 11, PART 1 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 9 OF 11)

401	153.07890	1.87	-3.78	-3.78	0.000
402	153.09890	1.87	-2.39	-2.39	0.000
403	153.11890	1.87	-1.59	-1.59	0.000
404	153.21890	1.87	-1.00	-1.00	0.000
405	153.31890	1.87	-0.80	-0.80	0.000
406	153.81890	1.87	-0.60	-0.60	0.000
407	160.91890	1.87	-0.40	-0.40	0.000
408	167.85890	1.87	-0.40	-0.40	0.000
409	167.87040	1.91	2.39	2.39	0.000
410	167.88540	1.96	4.58	4.58	0.000
411	167.91040	2.04	8.17	8.17	0.000
412	167.93540	2.12	10.56	10.56	0.000
413	167.96790	2.23	14.34	14.34	0.000
414	167.99540	2.32	17.33	17.33	0.000
415	168.02790	2.43	21.91	21.91	0.000
416	168.05290	2.51	26.89	26.89	0.000
417	168.06790	2.56	31.27	31.27	0.000
418	168.07040	2.56	24.90	24.90	0.000
419	168.07540	2.54	22.51	22.51	0.000
420	168.08040	2.52	19.92	19.92	0.000
421	168.08540	2.51	18.13	18.13	0.000
422	168.09540	2.47	14.94	14.94	0.000
423	168.10540	2.44	12.95	12.95	0.000
424	168.12540	2.37	9.76	9.76	0.000
425	168.15040	2.29	6.57	6.57	0.000
426	168.18040	2.19	3.78	3.78	0.000
427	168.21040	2.09	1.00	1.00	0.000
428	168.24290	1.98	-1.59	-1.59	0.000
429	168.27590	1.97	-4.18	-4.18	0.000
430	168.31590	1.96	-3.59	-3.59	0.000
431	168.35590	1.94	-3.19	-3.19	0.000
432	168.45590	1.90	-2.99	-2.99	0.000
433	168.55590	1.85	-2.59	-2.59	0.000
434	169.05590	1.63	-1.99	-1.99	0.000
435	172.65590	0.59	-1.39	-1.39	0.000
436	179.17590	0.00	-1.00	-1.00	0.000
437	179.18290	0.23	2.19	2.19	0.000
438	179.19290	0.57	5.38	5.38	0.000
439	179.20290	0.90	7.97	7.97	0.000
440	179.21290	1.23	10.36	10.36	0.000
441	179.23790	2.07	15.34	15.34	0.000
442	179.26790	3.07	20.72	20.72	0.000
443	179.29790	4.07	25.90	25.90	0.000
444	179.32790	5.07	31.47	31.47	0.000
445	179.34790	5.73	36.45	36.45	0.000
446	179.36790	6.40	42.63	42.63	0.000
447	179.38790	7.07	51.79	51.79	0.000
448	179.40290	7.57	61.35	61.35	0.000
449	179.41690	8.03	71.12	71.12	0.000
450	179.45690	8.03	50.00	50.00	0.000
451	179.65690	8.03	38.45	38.45	0.000
452	180.05690	8.03	33.47	33.47	0.000
453	180.85690	8.03	29.48	29.48	0.000
454	182.45690	8.03	26.49	26.49	0.000

TABLE 16. TEST NO. 11, PART 1 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 10 OF 11)

455	185.65690	8.03	24.10	24.10	0.000
456	192.05690	8.03	22.11	22.11	0.000
457	204.85690	8.03	20.72	20.72	0.000
458	211.21690	8.03	20.12	20.12	0.000
459	211.22290	7.83	14.54	14.54	0.000
460	211.23290	7.53	9.16	9.16	0.000
461	211.24790	7.00	4.58	4.58	0.000
462	211.27290	6.17	0.00	0.00	0.000
463	211.29790	6.14	-3.39	-3.39	0.000
464	211.32790	6.07	-5.98	-5.98	0.000
465	211.35790	6.05	-8.37	-8.37	0.000
466	211.37790	6.03	-5.98	-5.98	0.000
467	211.40290	6.02	-3.98	-3.98	0.000
468	211.42790	6.00	-3.39	-3.39	0.000
469	211.45690	5.98	-2.99	-2.99	0.000
470	211.89690	5.70	-1.20	-1.20	0.000
471	213.89690	4.60	-0.60	-0.60	0.000
472	229.89690	0.63	0.00	0.00	0.000
473	241.63690	0.00	0.00	0.00	0.000
474	241.66840	1.25	6.37	6.37	0.000
475	241.70840	2.39	14.14	14.14	0.000
476	241.74340	3.55	20.32	20.32	0.000
477	241.77840	4.72	26.49	26.49	0.000
478	241.80590	5.64	31.87	31.87	0.000
479	241.82840	6.39	37.65	37.65	0.000
480	241.84340	6.89	42.83	42.83	0.000
481	241.85840	7.39	49.60	49.60	0.000
482	241.86890	7.74	56.77	56.77	0.000
483	241.94890	7.74	38.65	38.65	0.000
484	242.04890	7.74	34.06	34.06	0.000
485	242.24890	7.74	30.48	30.48	0.000
486	242.64890	7.74	27.69	27.69	0.000
487	243.44890	7.74	24.90	24.90	0.000
488	245.04890	7.74	22.91	22.91	0.000
489	248.24890	7.74	21.31	21.31	0.000
490	254.64890	7.74	19.92	19.92	0.000
491	265.44890	7.74	19.12	19.12	0.000
492	269.66890	7.74	18.92	18.92	0.000
493	269.67340	7.54	15.54	15.54	0.000
494	269.68340	7.25	9.76	9.76	0.000
495	269.69340	6.92	5.98	5.98	0.000
496	269.70840	6.42	2.39	2.39	0.000
497	269.73340	6.33	-1.20	-1.20	0.000
498	269.75840	6.25	-4.18	-4.18	0.000
499	269.79340	6.08	-6.57	-6.57	0.000
500	269.82340	5.99	-4.58	-4.58	0.000
501	269.84840	5.98	-3.59	-3.59	0.000
502	269.87840	5.95	-2.99	-2.99	0.000
503	269.90940	5.80	-2.99	-2.99	0.000
504	270.06940	5.48	-1.59	-1.59	0.000
505	271.46940	3.15	-0.80	-0.80	0.000
506	275.46940	0.45	-0.40	-0.40	0.000
507	283.46940	0.00	0.00	0.00	0.000
508	7288.46940	0.00	0.00	0.00	0.000

TABLE 16. TEST NO. 11, PART 1 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 11 OF 11)

509	7288.48640	0.00	0.00	0.00	0.000
510	7288.49440	0.27	5.58	5.58	0.000
511	7288.50440	0.60	10.76	10.76	0.000
512	7288.51440	0.94	15.14	15.14	0.000
513	7288.52940	1.44	20.72	20.72	0.000
514	7288.54440	1.94	25.30	25.30	0.000
515	7288.56940	2.77	32.87	32.87	0.000
516	7288.59440	3.60	39.84	39.84	0.000
517	7288.61940	4.44	47.01	47.01	0.000
518	7288.64440	5.27	54.58	54.58	0.000
519	7288.66940	6.10	62.55	62.55	0.000
520	7288.67940	6.44	65.94	65.94	0.000
521	7288.69440	6.94	72.91	72.91	0.000
522	7288.70940	7.44	81.67	81.67	0.000
523	7288.72640	8.00	93.23	93.23	0.000
524	7289.02640	8.00	44.22	44.22	0.000
525	7289.52640	8.00	37.45	37.45	0.000
526	7290.52640	8.00	32.87	32.87	0.000
527	7292.52640	8.00	29.48	29.48	0.000
528	7296.52640	8.00	26.49	26.49	0.000
529	7304.52640	8.00	24.10	24.10	0.000
530	7320.52640	8.00	21.91	21.91	0.000
531	7352.52640	8.00	20.12	20.12	0.000
532	7352.53140	7.84	15.54	15.54	0.000
533	7352.53640	7.67	12.15	12.15	0.000
534	7352.54140	7.50	9.56	9.56	0.000
535	7352.54640	7.34	7.57	7.57	0.000
536	7352.55640	7.00	4.58	4.58	0.000
537	7352.56640	6.67	2.39	2.39	0.000
538	7352.58140	6.58	-0.20	-0.20	0.000
539	7352.60640	6.46	-0.40	-0.40	0.000
540	7352.63140	6.31	-7.37	-7.37	0.000
541	7352.65640	6.20	-9.96	-9.96	0.000
542	7352.68140	6.10	-12.55	-12.55	0.000
543	7352.69440	6.05	-13.74	-13.74	0.000
544	7352.70140	6.02	-9.96	-9.96	0.000
545	7352.71140	5.99	-5.98	-5.98	0.000
546	7352.71640	5.97	-4.98	-4.98	0.000
547	7352.72640	5.93	-3.98	-3.98	0.000
548	7352.74140	5.89	-3.39	-3.39	0.000
549	7352.76640	5.80	-2.99	-2.99	0.000
550	7352.77140	5.78	-1.79	-1.79	0.000
551	7352.80140	5.70	-1.00	-1.00	0.000
552	7352.88140	5.50	-0.60	-0.60	0.000
553	7362.56640	0.00	0.00	0.00	0.000

TABLE 17. TEST NO. 11, PART 2 - QUINLAN COMPLEX HISTORY FOR UTP-3001

T8714

Cycle		Rate, in./min.	Remarks
16	Load	0.02	
	unload	0.02	Approximately 30 min. rest after cycle
17	Load	0.02	
	unload	0.02	Approximately 30 min. rest after cycle
18	Load	0.05	
	relax	3 hr	
	unload	0.05	2 weeks rest after cycle
19	Load	0.02	
	unload	0.02	Approximately 30 min. rest after cycle
20	Load	0.02	
	unload	0.02	Approximately 30 min. rest after cycle
21	Load	0.05	
	relax	3 hr	
	unload	0.05	1 month rest after cycle
22-42	Cycling	5	Several cycles monitored followed by several with only maximum and minimum recorded.

Note: Part 3 of this test was continuing cycling to failure. The maximum and minimum values at larger intervals have been tabulated but not incorporated into the disk files.

3.1.12 Similitude Test No. 12

This similitude test and the one following it were run with the intent that only the strain-time history would be supplied to the subcontractors, who would then predict the stress-time histories from their respective predictive theories for the program review meeting held at the end of the phase II testing in September 1982.

This similitude test on the 6-in. bar specimens of UTP-3001 and UTP-19,360B propellants was: (1) a 0.01 in./min. ramp to 10% strain followed by relaxation; (2) a 1 in./min. unload to 5% strain and relaxation; and (3) 0.1 in./min. ramp to failure. The same test was repeated for ramp rates of 0.001, 0.1, and 0.01 in./min. The data as reported at the September meeting are shown for UTP-19,360B in Figure 33. The ramp rates were 0.01, 1, and 0.1 in./min. Tabular data for the test are given in Table 20.

(Text continued on page 88.)

TABLE 18. TEST NO. 11, PART 2 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 1 OF 10)

PROPELLANT: UTP 3001-750/7768
REQUESTOR: Carlton
WOR:

DATE: 1/4/82
OPERATOR: JWD

DEFINITIONS:
Time = Time From Start of Test (min)
σ = Stress (psi)
ε = Strain (%)
T(air) = Test Air Temperature (F)
T(prop) = Test Propellant Temperature (F)

RELATIONSHIPS:
σ = Force/Area
ε = Sample Extension/Length

NOMINAL VALUES:
Test Temp = 70 F
Gage Length = 6.00 in
Nom. Strain = 3,6,8 %
XHD Rate = .02 in/min

CALIBRATION DATA:	SAMPLE 1
Cal Wt = 10.0 lbs	
Load Cal (lbs/in)	10.000
Offset (in)	0.000
Temp (F) =	70.0

AREAS (sq in):		0.251
462	74387.32990	-0.170
463	74387.45790	2.540
464	74387.56390	-0.170
465	74387.68990	2.520
466	74387.81590	-0.160
467	74387.94190	2.500
468	74388.04790	-0.160

STRESS DATA (psi):

SET	Time	T(prop)	T(air)	Strain	SAMPLE 1	Avg	St Dev
1	18812.88140			0.00	0.00	0.00	0.000
2	18813.21640			0.11	0.00	0.00	0.000
3	18813.38140			0.17	0.64	0.64	0.000
4	18813.88140			0.33	1.75	1.75	0.000
5	18814.38140			0.50	2.63	2.63	0.000
6	18815.38140			0.83	4.06	4.06	0.000
7	18816.88140			1.33	5.98	5.98	0.000
8	18818.38140			1.83	7.89	7.89	0.000
9	18819.88140			2.33	9.80	9.80	0.000
10	18821.38140			2.83	11.95	11.95	0.000
11	18822.88140			3.33	14.10	14.10	0.000
12	18824.13140			3.75	15.86	15.86	0.000
13	18825.15140			4.09	17.13	17.13	0.000
14	18825.23140			4.06	15.94	15.94	0.000
15	18825.38140			4.01	14.66	14.66	0.000

TABLE 18. TEST NO. 11, PART 2 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 2 OF 10)

16	18825.53140	3.96	13.71	13.71	0.000
17	18825.68140	3.91	12.99	12.99	0.000
18	18825.88140	3.85	12.27	12.27	0.000
19	18826.38140	3.68	10.76	10.76	0.000
20	18826.88140	3.51	9.56	9.56	0.000
21	18827.63140	3.26	8.13	8.13	0.000
22	18828.38140	3.01	6.93	6.93	0.000
23	18829.13140	2.76	5.98	5.98	0.000
24	18829.88140	2.51	5.02	5.02	0.000
25	18831.13140	2.10	3.59	3.59	0.000
26	18832.38140	1.68	2.23	2.23	0.000
27	18833.63140	1.26	0.96	0.96	0.000
28	18834.88140	0.85	-0.24	-0.24	0.000
29	18835.88140	0.51	-1.27	-1.27	0.000
30	18837.04640	0.13	-2.39	-2.39	0.000
31	18837.38640	0.13	-1.91	-1.91	0.000
32	18837.98640	0.13	-1.59	-1.59	0.000
33	18838.78640	0.13	-1.43	-1.43	0.000
34	18839.58640	0.13	-1.27	-1.27	0.000
35	18840.38640	0.13	-1.12	-1.12	0.000
36	18842.38640	0.13	-0.96	-0.96	0.000
37	18845.38640	0.13	-0.80	-0.80	0.000
38	18850.38640	0.13	-0.56	-0.56	0.000
39	18858.38640	0.13	-0.40	-0.40	0.000
40	18868.22640	0.13	-0.40	-0.40	0.000
41	18868.62640	0.26	0.56	0.56	0.000
42	18869.62640	0.59	2.15	2.15	0.000
43	18871.12640	1.09	4.06	4.06	0.000
44	18873.62640	1.93	6.85	6.85	0.000
45	18877.12640	3.09	10.84	10.84	0.000
46	18880.62640	4.26	15.54	15.54	0.000
47	18884.12640	5.43	20.40	20.40	0.000
48	18886.62640	6.26	24.14	24.14	0.000
49	18888.62640	6.93	27.89	27.89	0.000
50	18890.12640	7.43	31.55	31.55	0.000
51	18891.62640	7.93	36.65	36.65	0.000
52	18893.62640	8.59	46.06	46.06	0.000
53	18895.47640	9.21	53.63	53.63	0.000
54	18895.62640	9.16	45.82	45.82	0.000
55	18896.12640	8.99	37.05	37.05	0.000
56	18896.62640	8.83	31.87	31.87	0.000
57	18897.12640	8.66	28.45	28.45	0.000
58	18898.12640	8.33	23.67	23.67	0.000
59	18899.12640	7.99	20.32	20.32	0.000
60	18900.62640	7.49	16.89	16.89	0.000
61	18902.12640	6.99	14.50	14.50	0.000
62	18904.12640	6.33	11.79	11.79	0.000
63	18907.12640	5.33	8.61	8.61	0.000
64	18911.12640	3.99	5.10	5.10	0.000
65	18916.12640	2.33	1.20	1.20	0.000
66	18922.27640	0.28	-3.43	-3.43	0.000
67	18922.41640	0.28	-3.19	-3.19	0.000
68	18922.81640	0.28	-2.87	-2.87	0.000
69	18923.81640	0.28	-2.47	-2.47	0.000

TABLE 18. TEST NO. 11, PART 2 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 3 OF 10)

70	18924.81640	0.28	-2.23	-2.23	0.000
71	18926.81640	0.28	-1.91	-1.91	0.000
72	18930.81640	0.28	-1.59	-1.59	0.000
73	18936.81640	0.28	-1.27	-1.27	0.000
74	18946.81640	0.28	-1.04	-1.04	0.000
75	18955.05640	0.28	-0.96	-0.96	0.000
76	18955.21640	0.41	0.32	0.32	0.000
77	18955.61640	0.74	1.83	1.83	0.000
78	18956.21640	1.24	3.82	3.82	0.000
79	18957.21640	2.08	6.85	6.85	0.000
80	18958.61640	3.24	10.76	10.76	0.000
81	18959.81640	4.24	14.02	14.02	0.000
82	18960.81640	5.08	16.89	16.89	0.000
83	18961.81640	5.91	20.16	20.16	0.000
84	18962.81640	6.74	24.14	24.14	0.000
85	18963.81640	7.58	29.48	29.48	0.000
86	18964.61640	8.24	35.78	35.78	0.000
87	18964.81640	8.24	33.47	33.47	0.000
88	18965.21640	8.24	31.71	31.71	0.000
89	18966.01640	8.24	29.96	29.96	0.000
90	18967.61640	8.24	28.29	28.29	0.000
91	18970.81640	8.24	26.85	26.85	0.000
92	18977.21640	8.24	25.26	25.26	0.000
93	18990.01640	8.24	23.27	23.27	0.000
94	19015.61640	8.24	21.83	21.83	0.000
95	19066.81640	8.24	20.56	20.56	0.000
96	19144.45640	8.24	19.76	19.76	0.000
97	19144.61640	8.11	17.21	17.21	0.000
98	19144.81640	7.94	15.30	15.30	0.000
99	19145.21640	7.61	12.83	12.83	0.000
100	19145.81640	7.11	10.36	10.36	0.000
101	19146.41640	6.61	8.37	8.37	0.000
102	19147.01640	6.11	6.77	6.77	0.000
103	19147.81640	5.44	4.94	4.94	0.000
104	19148.81640	4.61	2.87	2.87	0.000
105	19150.81640	2.94	-0.80	-0.80	0.000
106	19152.81640	1.28	-4.38	-4.38	0.000
107	19154.01640	0.28	-6.61	-6.61	0.000
108	19154.21640	0.28	-5.66	-5.66	0.000
109	19154.61640	0.28	-5.10	-5.10	0.000
110	19155.21640	0.28	-4.62	-4.62	0.000
111	19156.01640	0.28	-4.22	-4.22	0.000
112	19157.21640	0.28	-3.75	-3.75	0.000
113	19158.81640	0.28	-3.43	-3.43	0.000
114	19160.81640	0.28	-3.11	-3.11	0.000
115	19164.81640	0.28	-2.63	-2.63	0.000
116	19168.81640	0.28	-2.39	-2.39	0.000
117	19172.81640	0.28	-2.23	-2.23	0.000
118	32622.81640	0.00	0.00	0.00	0.000
119	32623.31640	0.16	1.99	1.99	0.000
120	32624.31640	0.50	3.98	3.98	0.000
121	32625.31640	0.83	5.90	5.90	0.000
122	32626.81640	1.33	8.53	8.53	0.000
123	32628.81640	2.00	11.95	11.95	0.000

TABLE 18. TEST NO. 11, PART 2 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 4 OF 10)

124	32630.81640	2.66	14.90	14.90	0.000
125	32632.81640	3.33	17.85	17.85	0.000
126	32634.46640	3.88	20.16	20.16	0.000
127	32634.81640	3.76	15.94	15.94	0.000
128	32635.31640	3.60	13.47	13.47	0.000
129	32635.81640	3.43	11.71	11.71	0.000
130	32636.81640	3.10	9.24	9.24	0.000
131	32637.81640	2.76	7.49	7.49	0.000
132	32640.31640	1.93	3.90	3.90	0.000
133	32642.81640	1.10	0.80	0.80	0.000
134	32645.96640	0.05	-2.55	-2.55	0.000
135	32646.06640	0.05	-2.23	-2.23	0.000
136	32646.56640	0.05	-1.83	-1.83	0.000
137	32647.06640	0.05	-1.59	-1.59	0.000
138	32647.56640	0.05	-1.43	-1.43	0.000
139	32648.56640	0.05	-1.27	-1.27	0.000
140	32650.56640	0.05	-0.96	-0.96	0.000
141	32653.56640	0.05	-0.80	-0.80	0.000
142	32659.56640	0.05	-0.48	-0.48	0.000
143	32665.56640	0.05	-0.32	-0.32	0.000
144	32676.16640	0.05	-0.24	-0.24	0.000
145	32676.36640	0.11	0.48	0.48	0.000
146	32676.86640	0.28	1.59	1.59	0.000
147	32677.86640	0.61	3.27	3.27	0.000
148	32680.36640	1.45	6.53	6.53	0.000
149	32682.86640	2.28	9.96	9.96	0.000
150	32685.36640	3.11	13.55	13.55	0.000
151	32687.86640	3.95	17.37	17.37	0.000
152	32690.36640	4.78	21.27	21.27	0.000
153	32692.86640	5.61	25.58	25.58	0.000
154	32695.36640	6.45	30.84	30.84	0.000
155	32697.86640	7.28	38.01	38.01	0.000
156	32700.36640	8.11	49.08	49.08	0.000
157	32701.86640	8.61	57.37	57.37	0.000
158	32702.81640	8.93	62.15	62.15	0.000
159	32703.11640	8.83	49.00	49.00	0.000
160	32703.36640	8.75	43.82	43.82	0.000
161	32703.86640	8.58	37.21	37.21	0.000
162	32704.36640	8.41	32.67	32.67	0.000
163	32705.36640	8.08	26.93	26.93	0.000
164	32706.36640	7.75	23.11	23.11	0.000
165	32707.86640	7.25	18.96	18.96	0.000
166	32709.36640	6.75	16.02	16.02	0.000
167	32710.86640	6.25	13.63	13.63	0.000
168	32712.86640	5.58	11.08	11.08	0.000
169	32715.36640	4.75	8.29	8.29	0.000
170	32717.86640	3.91	5.98	5.98	0.000
171	32722.86640	2.25	1.67	1.67	0.000
172	32727.86640	0.58	-2.39	-2.39	0.000
173	32729.31640	0.10	-3.90	-3.90	0.000
174	32729.41640	0.10	-3.59	-3.59	0.000
175	32729.91640	0.10	-3.19	-3.19	0.000
176	32730.41640	0.10	-2.95	-2.95	0.000
177	32731.41640	0.10	-2.63	-2.63	0.000

TABLE 18. TEST NO. 11, PART 2 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 5 OF 10)

178	32732.41640	0.10	-2.39	-2.39	0.000
179	32734.41640	0.10	-2.15	-2.15	0.000
180	32737.41640	0.10	-1.91	-1.91	0.000
181	32741.41640	0.10	-1.67	-1.67	0.000
182	32746.41640	0.10	-1.51	-1.51	0.000
183	32751.41640	0.10	-1.35	-1.35	0.000
184	32758.41640	0.10	-1.20	-1.20	0.000
185	32758.61640	0.26	0.20	0.20	0.000
186	32759.01640	0.60	2.19	2.19	0.000
187	32760.01640	1.43	5.78	5.78	0.000
188	32761.01640	2.26	9.46	9.36	0.000
189	32762.01640	3.10	12.55	12.55	0.000
190	32763.01640	3.93	15.74	15.74	0.000
191	32764.01640	4.76	18.73	18.73	0.000
192	32765.01640	5.60	22.71	22.71	0.000
193	32766.01640	6.43	27.49	27.49	0.000
194	32767.01640	7.26	34.26	34.26	0.000
195	32767.83640	7.95	42.23	42.23	0.000
196	32768.23640	7.95	38.25	38.25	0.000
197	32768.73640	7.95	35.86	35.86	0.000
198	32770.73640	7.95	32.07	32.07	0.000
199	32774.73640	7.95	29.08	29.08	0.000
200	32782.73640	7.95	26.49	26.49	0.000
201	32798.73640	7.95	24.70	24.70	0.000
202	32830.73640	7.95	22.91	22.91	0.000
203	32894.73640	7.95	21.31	21.31	0.000
204	32947.73640	7.95	20.52	20.52	0.000
205	32947.93640	7.78	16.93	16.93	0.000
206	32948.13640	7.61	15.14	15.14	0.000
207	32948.53640	7.28	12.55	12.55	0.000
208	32948.93640	6.95	10.56	10.56	0.000
209	32949.53640	6.45	8.37	8.37	0.000
210	32949.93640	6.11	6.97	6.97	0.000
211	32950.36640	5.75	5.98	5.98	0.000
212	32951.13640	5.11	3.98	3.98	0.000
213	32951.93640	4.45	1.99	1.99	0.000
214	32952.93640	3.61	0.00	0.00	0.000
215	32953.93640	2.78	-1.99	-1.99	0.000
216	32954.93640	1.95	-3.78	-3.78	0.000
217	32955.93640	1.11	-5.78	-5.78	0.000
218	32957.13640	0.11	-8.17	-8.17	0.000
219	32957.33640	0.11	-7.17	-7.17	0.000
220	32957.53640	0.11	-6.57	-6.57	0.000
221	32957.83640	0.11	-6.18	-6.18	0.000
222	32958.13640	0.11	-5.98	-5.98	0.000
223	32958.63640	0.11	-5.58	-5.58	0.000
224	32959.13640	0.11	-5.38	-5.38	0.000
225	32960.13640	0.11	-4.78	-4.78	0.000
226	32961.13640	0.11	-4.58	-4.58	0.000
227	32963.13640	0.11	-3.98	-3.98	0.000
228	32966.13640	0.11	-3.78	-3.78	0.000
229	32971.13640	0.11	-3.19	-3.19	0.000
230	32976.13640	0.11	-2.99	-2.99	0.000
231	32983.13640	0.11	-2.79	-2.79	0.000

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TABLE 18. TEST NO. 11, PART 2 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 6 OF 10)

232	74383.13640	0.00	0.00	0.00	0.000
233	74383.15140	0.00	0.00	0.00	0.000
234	74383.15640	0.42	12.75	12.75	0.000
235	74383.16140	0.84	22.71	22.71	0.000
236	74383.16640	1.25	31.08	31.08	0.000
237	74383.17640	2.09	45.42	45.42	0.000
238	74383.19140	3.34	62.95	62.95	0.000
239	74383.20640	4.59	82.47	82.47	0.000
240	74383.22140	5.84	102.79	102.79	0.000
241	74383.23640	7.09	126.69	126.69	0.000
242	74383.25140	8.34	154.18	154.18	0.000
243	74383.26640	9.59	175.30	175.30	0.000
244	74383.28140	10.84	190.04	190.04	0.000
245	74383.29740	12.17	200.80	200.80	0.000
246	74383.29890	12.04	157.37	157.37	0.000
247	74383.30140	11.84	113.94	113.94	0.000
248	74383.30640	11.42	81.67	81.67	0.000
249	74383.31140	11.00	63.74	63.74	0.000
250	74383.31640	10.64	51.39	51.39	0.000
251	74383.32640	9.75	36.25	36.25	0.000
252	74383.33640	9.00	26.69	26.69	0.000
253	74383.35140	8.00	17.13	17.13	0.000
254	74383.37640	5.70	5.98	5.98	0.000
255	74383.40140	3.30	-2.79	-2.79	0.000
256	74383.42990	0.85	-12.75	-12.75	0.000
257	74383.43940	1.90	-3.59	-3.59	0.000
258	74383.44940	2.50	4.38	4.38	0.000
259	74383.46440	3.60	16.33	16.33	0.000
260	74383.48440	5.10	28.69	28.69	0.000
261	74383.50440	6.75	39.84	39.84	0.000
262	74383.51940	7.90	50.60	50.60	0.000
263	74383.53440	8.90	64.54	64.54	0.000
264	74383.54440	9.80	77.29	77.29	0.000
265	74383.55440	10.60	94.82	94.82	0.000
266	74383.56440	11.30	119.52	119.52	0.000
267	74383.56940	11.80	135.06	135.06	0.000
268	74383.57640	12.17	156.57	156.57	0.000
269	74383.57940	11.80	100.00	100.00	0.000
270	74383.58440	11.20	71.71	71.71	0.000
271	74383.58940	10.80	56.18	56.18	0.000
272	74383.59440	10.50	46.61	46.61	0.000
273	74383.60440	9.50	32.67	32.67	0.000
274	74383.61440	8.80	23.90	23.90	0.000
275	74383.62440	7.80	17.53	17.53	0.000
276	74383.64440	6.10	8.37	8.37	0.000
277	74383.67440	3.40	-2.39	-2.39	0.000
278	74383.69940	1.20	-9.56	-9.56	0.000
279	74383.70740	1.80	-2.79	-2.79	0.000
280	74383.72240	2.90	8.37	8.37	0.000
281	74383.73740	4.00	18.73	18.73	0.000
282	74383.75740	5.50	29.48	29.48	0.000
283	74383.77740	6.90	40.64	40.64	0.000
284	74383.79240	8.20	51.39	51.39	0.000
285	74383.80740	9.50	66.53	66.53	0.000

TABLE 18. TEST NO. 11, PART 2 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 7 OF 10)

286	74383.81740	10.30	80.08	80.08	0.000
287	74383.82740	11.10	100.40	100.40	0.000
288	74383.83240	11.40	114.74	114.74	0.000
289	74383.83990	12.17	140.24	140.24	0.000
290	74383.84240	11.80	99.60	99.60	0.000
291	74383.84740	11.20	69.72	69.72	0.000
292	74383.85240	11.10	54.58	54.58	0.000
293	74383.86240	10.20	37.05	37.05	0.000
294	74383.87240	9.40	27.09	27.09	0.000
295	74383.88740	8.00	17.13	17.13	0.000
296	74383.91240	5.70	5.98	5.98	0.000
297	74383.93740	3.60	-2.39	-2.39	0.000
298	74383.95990	1.50	-8.76	-8.76	0.000
299	74383.97490	2.80	2.39	2.39	0.000
300	74383.98990	3.90	12.75	12.75	0.000
301	74384.00490	5.10	21.91	21.91	0.000
302	74384.02990	6.80	35.06	35.06	0.000
303	74384.04490	8.00	43.82	43.82	0.000
304	74384.05990	9.00	55.78	55.78	0.000
305	74384.06990	9.80	66.53	66.53	0.000
306	74384.07990	10.50	81.67	81.67	0.000
307	74384.08990	11.35	103.59	103.59	0.000
308	74384.09490	11.70	121.51	121.51	0.000
309	74384.09790	12.17	130.68	130.68	0.000
310	74384.09990	12.00	102.39	102.39	0.000
311	74384.10490	11.60	70.12	70.12	0.000
312	74384.10990	11.20	53.78	53.78	0.000
313	74384.11990	10.50	36.65	36.65	0.000
314	74384.12990	9.50	26.69	26.69	0.000
315	74384.13990	8.60	19.52	19.52	0.000
316	74384.15990	6.70	9.96	9.96	0.000
317	74384.18490	4.20	0.80	0.80	0.000
318	74384.21190	1.70	-7.97	-7.97	0.000
319	74384.22190	2.30	0.00	0.00	0.000
320	74384.23190	2.90	6.77	6.77	0.000
321	74384.24690	4.20	16.73	16.73	0.000
322	74384.26190	5.20	24.70	24.70	0.000
323	74384.28190	6.90	35.06	35.06	0.000
324	74384.29690	8.10	44.22	44.22	0.000
325	74384.30690	9.00	52.59	52.59	0.000
326	74384.31690	9.75	61.75	61.75	0.000
327	74384.32690	10.50	75.70	75.70	0.000
328	74384.33690	11.30	95.62	95.62	0.000
329	74384.34190	11.90	109.56	109.56	0.000
330	74384.34640	12.17	124.70	124.70	0.000
331	74384.34940	11.80	87.65	87.65	0.000
332	74384.35190	11.60	73.70	73.70	0.000
333	74384.35690	11.25	56.18	56.18	0.000
334	74384.36160	10.70	45.82	45.82	0.000
335	74384.36690	10.40	37.45	37.45	0.000
336	74384.37190	10.00	31.47	31.47	0.000
337	74384.38190	9.00	22.71	22.71	0.000
338	74384.39190	8.30	16.73	16.73	0.000
339	74384.41190	6.50	7.97	7.97	0.000

TABLE 18. TEST NO. 11, PART 2 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 8 OF 10)

340	74384.43690	4.20	-0.80	-0.80	0.000
341	74384.45990	1.80	-7.97	-7.97	0.000
342	74384.46890	2.30	-1.20	-1.20	0.000
343	74384.48390	3.60	8.76	8.76	0.000
344	74384.49890	4.50	19.12	19.12	0.000
345	74384.51390	5.70	27.09	27.09	0.000
346	74384.52890	7.00	34.26	34.26	0.000
347	74384.54390	8.30	42.23	42.23	0.000
348	74384.55390	8.90	49.80	49.80	0.000
349	74384.56390	9.90	58.96	58.96	0.000
350	74384.57390	10.50	71.31	71.31	0.000
351	74384.58390	11.50	90.04	90.04	0.000
352	74384.58890	11.80	102.79	102.79	0.000
353	74384.59490	12.17	121.12	121.12	0.000
354	74384.59890	11.60	76.89	76.89	0.000
355	74384.60390	11.20	57.77	57.77	0.000
356	74384.60890	10.90	45.82	45.82	0.000
357	74384.61390	10.50	37.85	37.85	0.000
358	74384.62390	9.50	27.49	27.49	0.000
359	74384.63390	8.90	19.92	19.92	0.000
360	74384.64890	7.60	12.35	12.35	0.000
361	74384.67390	5.60	4.38	4.38	0.000
362	74384.69390	3.90	-2.39	-2.39	0.000
363	74384.71390	1.90	-7.97	-7.97	0.000
364	74384.71890	2.20	-3.59	-3.59	0.000
365	74384.72890	3.00	4.38	4.38	0.000
366	74384.73890	3.70	11.16	11.16	0.000
367	74384.74890	4.50	17.53	17.53	0.000
368	74384.76390	5.90	25.90	25.90	0.000
369	74384.77890	6.90	32.67	32.67	0.000
370	74384.79390	8.10	41.83	41.83	0.000
371	74384.80390	9.30	48.21	48.21	0.000
372	74384.81390	9.80	56.57	56.57	0.000
373	74384.82390	10.80	68.53	68.53	0.000
374	74384.83390	11.60	85.66	85.66	0.000
375	74384.83890	11.90	98.80	98.80	0.000
376	74384.84540	12.17	117.13	117.13	0.000
377	74384.84890	11.60	78.09	78.09	0.000
378	74384.85390	11.10	57.37	57.37	0.000
379	74384.85890	10.60	45.42	45.42	0.000
380	74384.86890	9.70	31.87	31.87	0.000
381	74384.87890	9.00	23.51	23.51	0.000
382	74384.89390	7.60	14.74	14.74	0.000
383	74384.91390	5.80	6.77	6.77	0.000
384	74384.93390	4.00	-0.40	-0.40	0.000
385	74384.95640	2.00	-7.17	-7.17	0.000
386	74384.96640	2.60	0.40	0.40	0.000
387	74384.97640	3.40	6.77	6.77	0.000
388	74384.98640	4.20	13.94	13.94	0.000
389	74384.99640	4.80	19.52	19.52	0.000
390	74385.01140	6.00	27.89	27.89	0.000
391	74385.02640	6.60	34.66	34.66	0.000
392	74385.04140	7.80	42.63	42.63	0.000
393	74385.05140	8.70	50.60	50.60	0.000

TABLE 18. TEST NO. 11, PART 2 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 9 OF 10)

394	74385.06140	9.40	60.16	60.16	0.000
395	74385.07140	10.25	73.31	73.31	0.000
396	74385.08140	11.10	93.63	93.63	0.000
397	74385.08640	11.60	108.37	108.37	0.000
398	74385.08890	12.17	115.54	115.54	0.000
399	74385.09390	11.80	72.51	72.51	0.000
400	74385.10390	11.20	43.82	43.82	0.000
401	74385.11390	10.60	30.68	30.68	0.000
402	74385.12390	9.60	22.31	22.31	0.000
403	74385.14390	7.90	11.95	11.95	0.000
404	74385.17390	5.30	0.80	0.80	0.000
405	74385.20090	2.10	-7.17	-7.17	0.000
406	74385.21390	2.70	3.19	3.19	0.000
407	74385.23390	3.90	17.13	17.13	0.000
408	74385.25390	5.50	28.29	28.29	0.000
409	74385.27390	7.20	37.85	37.85	0.000
410	74385.29390	8.80	51.00	51.00	0.000
411	74385.30390	10.00	59.76	59.76	0.000
412	74385.31390	10.60	74.50	74.50	0.000
413	74385.32390	11.70	95.62	95.62	0.000
414	74385.32890	12.17	112.35	112.35	0.000
415	74385.33390	11.80	63.74	63.74	0.000
416	74385.34390	10.80	40.64	40.64	0.000
417	74385.35390	10.20	29.08	29.08	0.000
418	74385.36390	9.10	21.51	21.51	0.000
419	74385.37390	8.30	15.14	15.14	0.000
420	74385.40390	5.20	3.59	3.59	0.000
421	74385.43890	2.15	-7.57	-7.57	0.000
422	74385.45690	3.30	3.98	3.98	0.000
423	74385.47690	4.70	16.73	16.73	0.000
424	74385.50690	7.00	32.27	32.27	0.000
425	74385.52690	8.50	43.82	43.82	0.000
426	74385.54690	10.00	61.75	61.75	0.000
427	74385.55690	10.90	75.70	75.70	0.000
428	74385.56990	12.17	110.36	110.36	0.000
429	74385.57190	11.80	77.29	77.29	0.000
430	74385.57690	11.20	55.78	55.78	0.000
431	74385.58690	10.60	37.45	37.45	0.000
432	74385.59690	9.80	26.69	26.69	0.000
433	74385.61690	8.30	15.14	15.14	0.000
434	74385.64690	5.50	2.39	2.39	0.000
435	74385.67790	2.21	-7.17	-7.17	0.000
436	74385.69590	3.40	4.78	4.78	0.000
437	74385.71590	4.70	17.13	17.13	0.000
438	74385.73590	6.30	27.09	27.09	0.000
439	74385.75590	7.80	38.65	38.65	0.000
440	74385.77590	9.30	52.59	52.59	0.000
441	74385.78590	10.30	62.95	62.95	0.000
442	74385.79590	10.90	79.68	79.68	0.000
443	74385.80690	12.17	108.37	108.37	0.000
444	74385.81090	11.70	70.92	70.92	0.000
445	74385.81590	11.00	49.80	49.80	0.000
446	74385.82590	10.20	33.86	33.86	0.000
447	74385.83590	9.50	23.90	23.90	0.000

TABLE 18. TEST NO. 11, PART 2 - 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 10 OF 10)

448	74385.85590	8.10	13.15	13.15	0.000
449	74385.88590	5.00	1.20	1.20	0.000
450	74385.91590	2.26	-7.17	-7.17	0.000
451	74386.04490	12.17	108.37	108.37	0.000
452	74386.15390	2.33	-6.77	-6.77	0.000
453	74386.28290	12.17	107.17	107.17	0.000
454	74386.39190	2.34	-6.77	-6.77	0.000
455	74386.52090	12.17	105.58	105.58	0.000
456	74386.62890	2.40	-6.77	-6.77	0.000
457	74386.75690	12.17	104.78	104.78	0.000
458	74386.86390	2.40	-6.77	-6.77	0.000
459	74386.98990	12.17	103.59	103.59	0.000
460	74387.09690	2.40	-6.77	-6.77	0.000
461	74387.22390	12.17	102.39	102.39	0.000
462	74387.32990	2.40	-6.77	-6.77	0.000
463	74387.45790	12.17	101.19	101.19	0.000
464	74387.56390	2.40	-6.77	-6.77	0.000
465	74387.68990	12.17	100.40	100.40	0.000
466	74387.81590	2.40	-6.37	-6.37	0.000
467	74387.94190	12.17	99.60	99.60	0.000
468	74388.04790	2.40	-6.37	-6.37	0.000

TABLE 19. TEST NO. 11, PART 3 - UTP-3001-750/7768 1/2-IN.
BAR STRESS WHILE CYCLING

(SHEET 1 OF 2)

T8715

Time	Strain	Stress	Remarks
74388.0479	2.40	-6.37	End of cycle 20
74390.3479	12.17	93.23	Peak of cycle 30
74390.4539	2.40	-5.98	End of cycle 30
74391.3819	12.17	92.03	Peak of cycle 34
74391.4239	2.40	-5.58	End of cycle 34
74391.9432	12.17	91.24	Peak of cycle 40
74391.9859	2.40	-5.58	End of cycle 40
74392.0799	12.17	89.64	Peak of cycle 50
74392.1219	2.40	-5.18	End of cycle 50
74393.0099	12.17	88.45	Peak of cycle 60
74393.0519	2.40	-5.18	End of cycle 60
74394.7799	12.17	84.86	Peak of cycle 80
74394.8219	2.40	-4.78	End of cycle 80
74395.7279	12.17	80.10	Peak of cycle 102
74395.7479	2.40	-4.78	End of cycle 102
74418.3479	12.17	76.49	Peak of cycle 164
74418.3979	2.40	-4.78	End of cycle 164
74451.5979	12.17	71.71	Peak of cycle 330
74451.8779	2.40	-4.38	End of cycle 330
74474.2779	12.17	68.92	Peak of cycle 442
74474.3179	2.40	-3.98	End of cycle 442
74698.0179	12.17	62.95	Peak of cycle 980
	2.40	-3.59	End of cycle 980
74928.0179	12.17	60.16	Peak of cycle 1980
	2.40	-3.59	End of cycle 1980
75158.0179	12.17	56.97	Peak of cycle 2980
	2.40	-3.59	End of cycle 2980
75388.0179	12.17	56.18	Peak of cycle 3980
	2.40	-3.59	End of cycle 3980

TABLE 19. TEST NO. 11, PART 3 - UTP-3001-750/7768 1/2-IN.
BAR STRESS WHILE CYCLING
(SHEET 2 OF 2)

T8715

Time	Strain	Stress	Remarks
75618.0179	12.17	53.39	Peak of cycle 4980
	2.40	-3.59	End of cycle 4980
75695.5179	12.17	51.39	Peak of cycle 5317
	2.40	-3.59	End of cycle 5317
		SAMPLE BROKE	

3.1.13 Three-Step Relaxation Test No. 13

The three-step relaxation tests were run as similitude tests in which the strain-time data were reported to the subcontractors and they were to predict the stress-time histories. The test consisted of loading 6-in. bar specimens at 0.05 in./min. crosshead rate to 10%, relaxing 1 hr, unloading at the same rate to 7% strain, relaxing 1 hr, and repeating the process at 3% strain, then unload. The tests were then repeated with nominal 24 hr relaxation periods for both UTP-3001 and UTP-19,360B propellants.

These data were reworked to make sure that peak and minimum stress points were included in the data. Relaxation was monitored after the sample was unloaded to zero stress. Data for UTP-3001 is shown in Figure 34 with the 1 hr relaxation periods. Tabular data are given in Table 21.

(Text continued on page 103.)

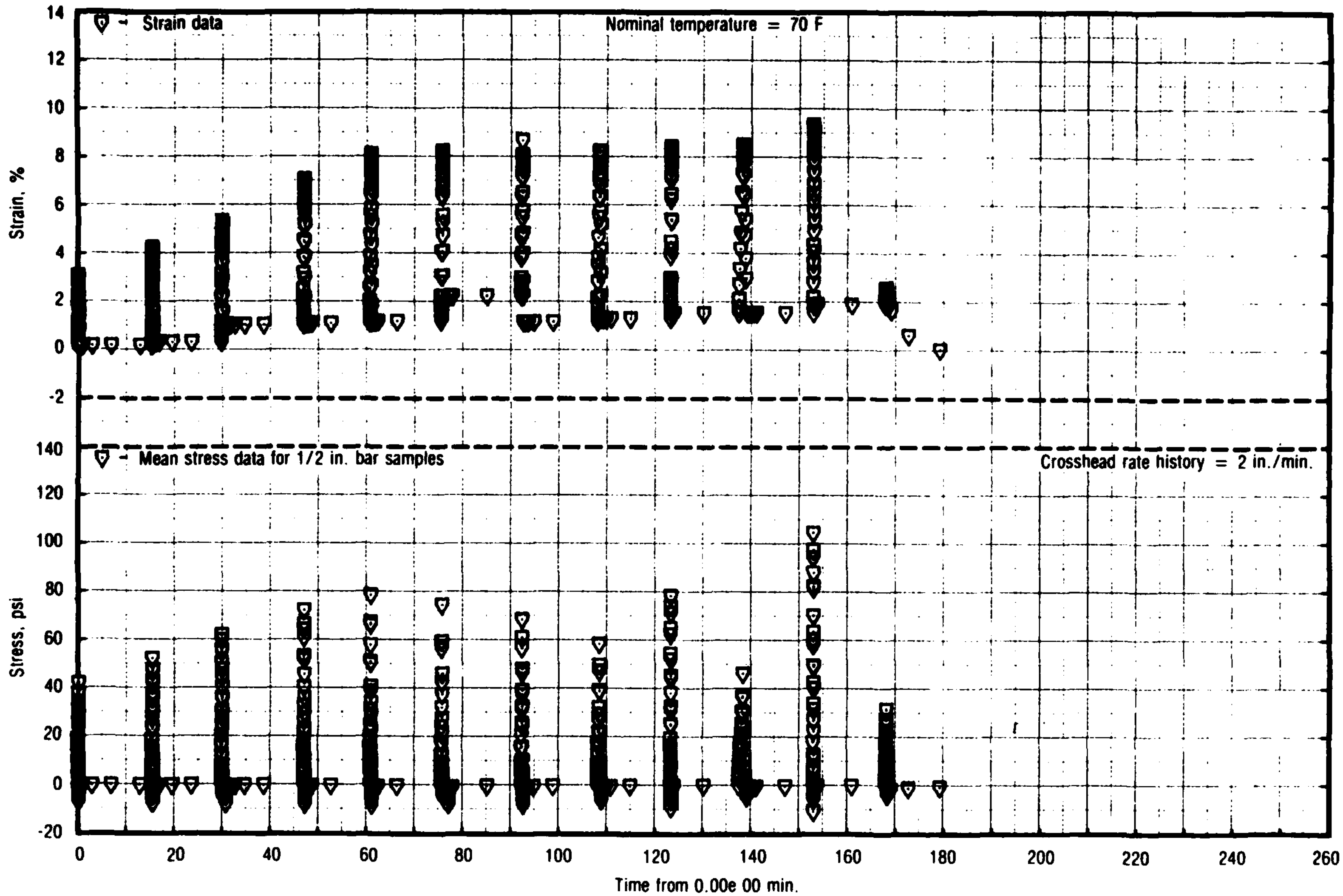


Figure 26. Test No. 11, Part 1 - Stress While Cycling for UTP-3001-750/7768

28757

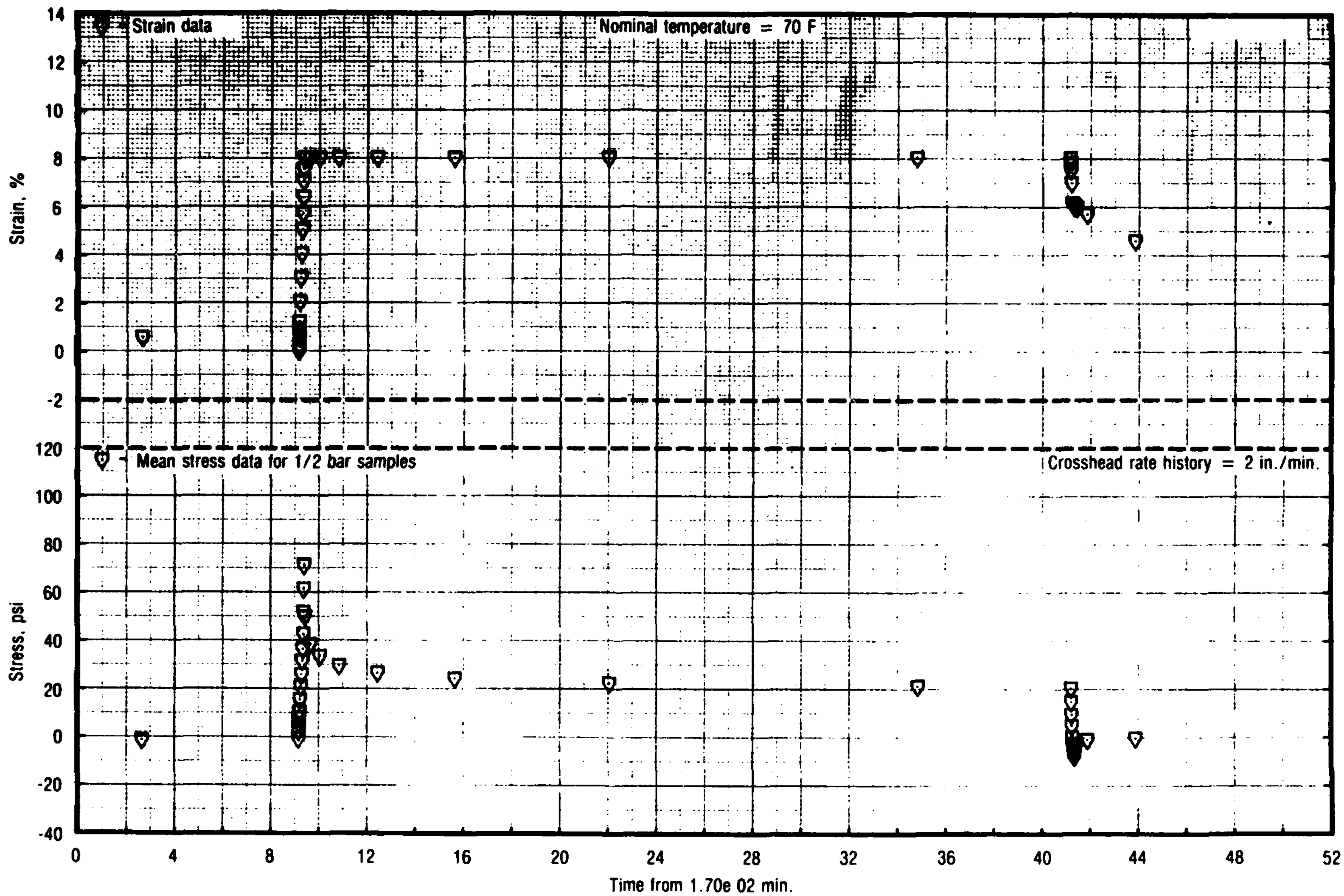


Figure 27. Test No. 11, Part 1 - Stress While Cycling for UTP-3001-750/7768

28758

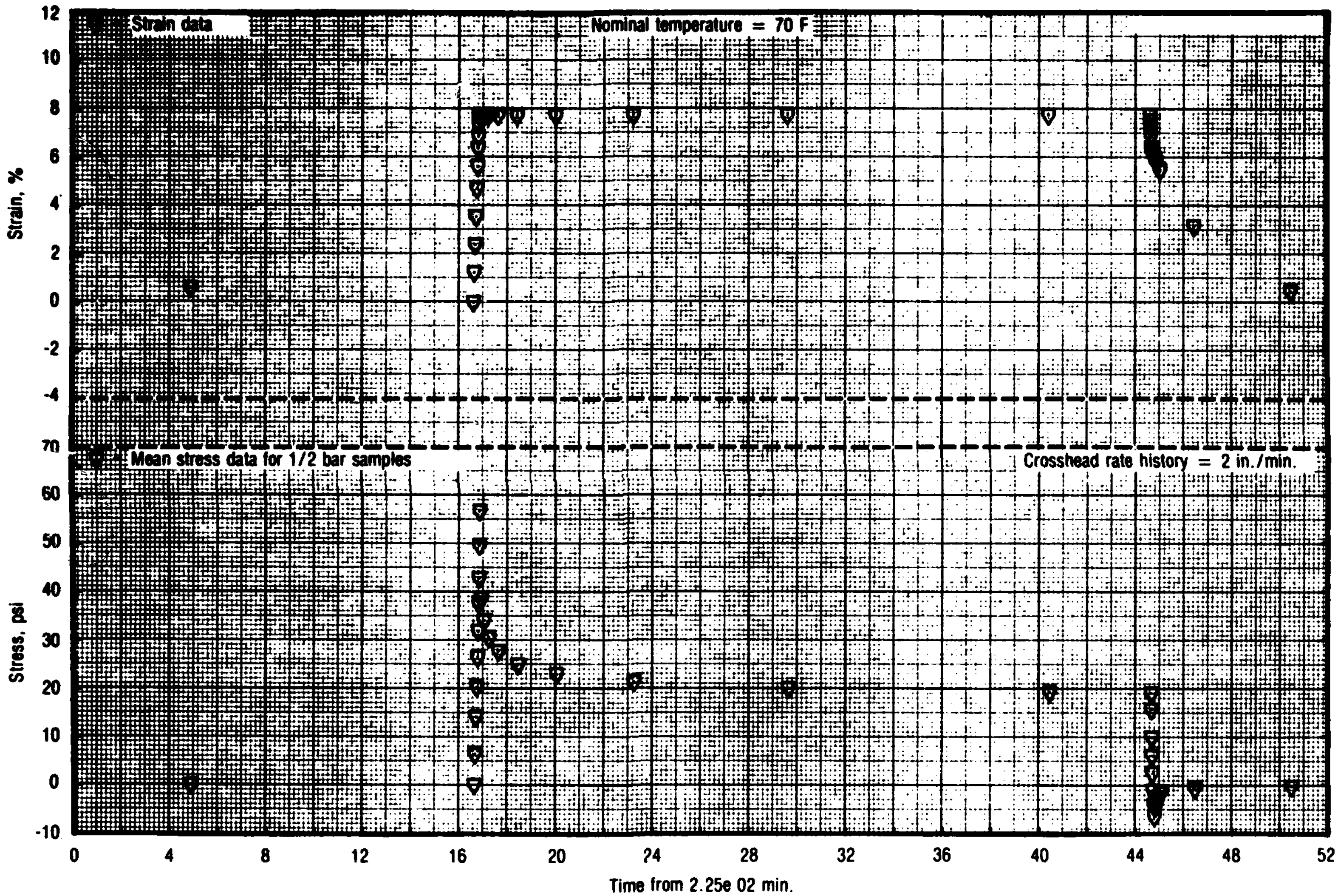


Figure 28. Test No. 11, Part 1 - Stress While Cycling for UTP-3001-750/7768

28797

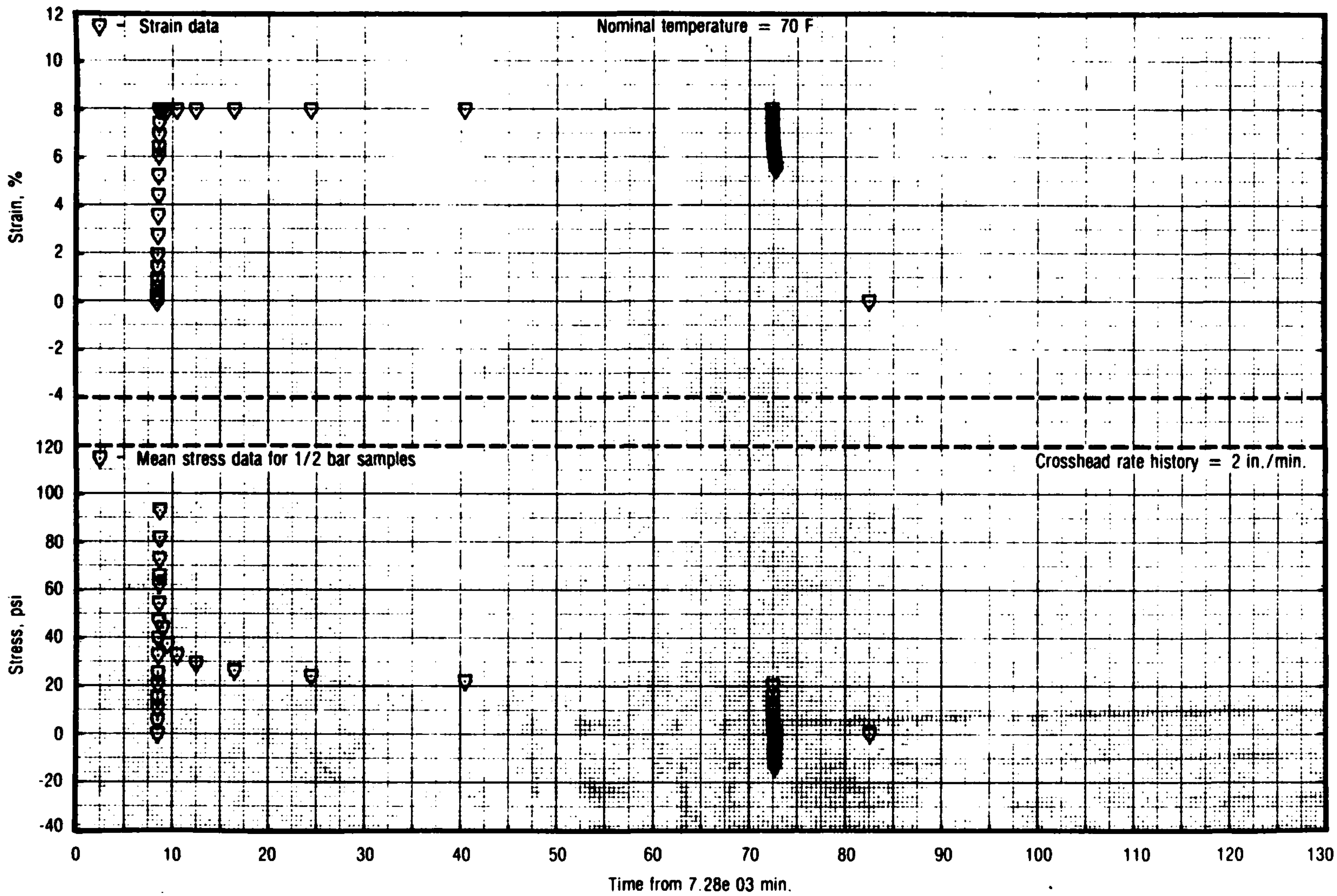


Figure 29. Test No. 11, Part 1 - Stress While Cycling for UTP-3001-750/7768

28798

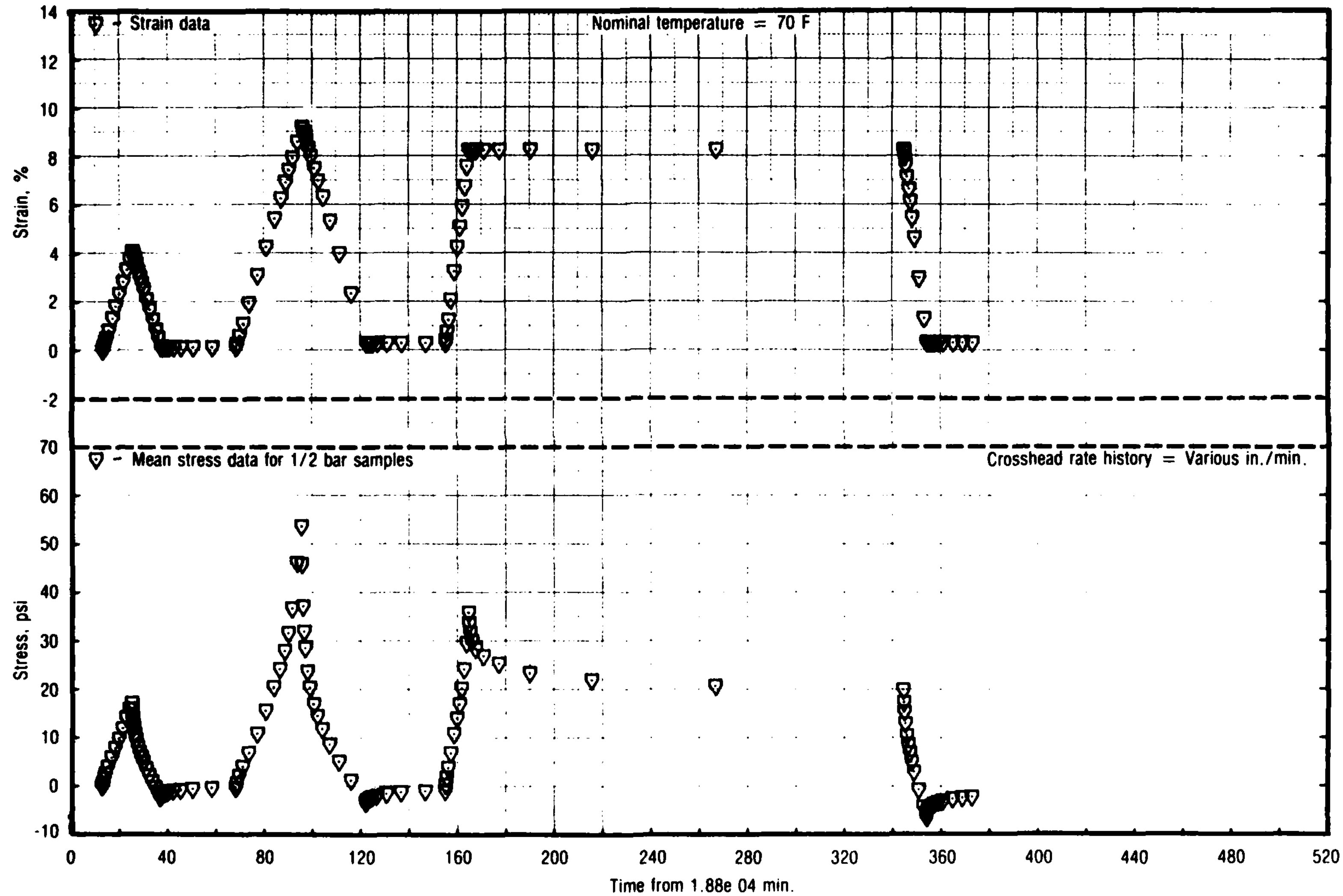


Figure 30. Test No. 11, Part 2 - Stress While Cycling for UTP-3001-750/7768

28759

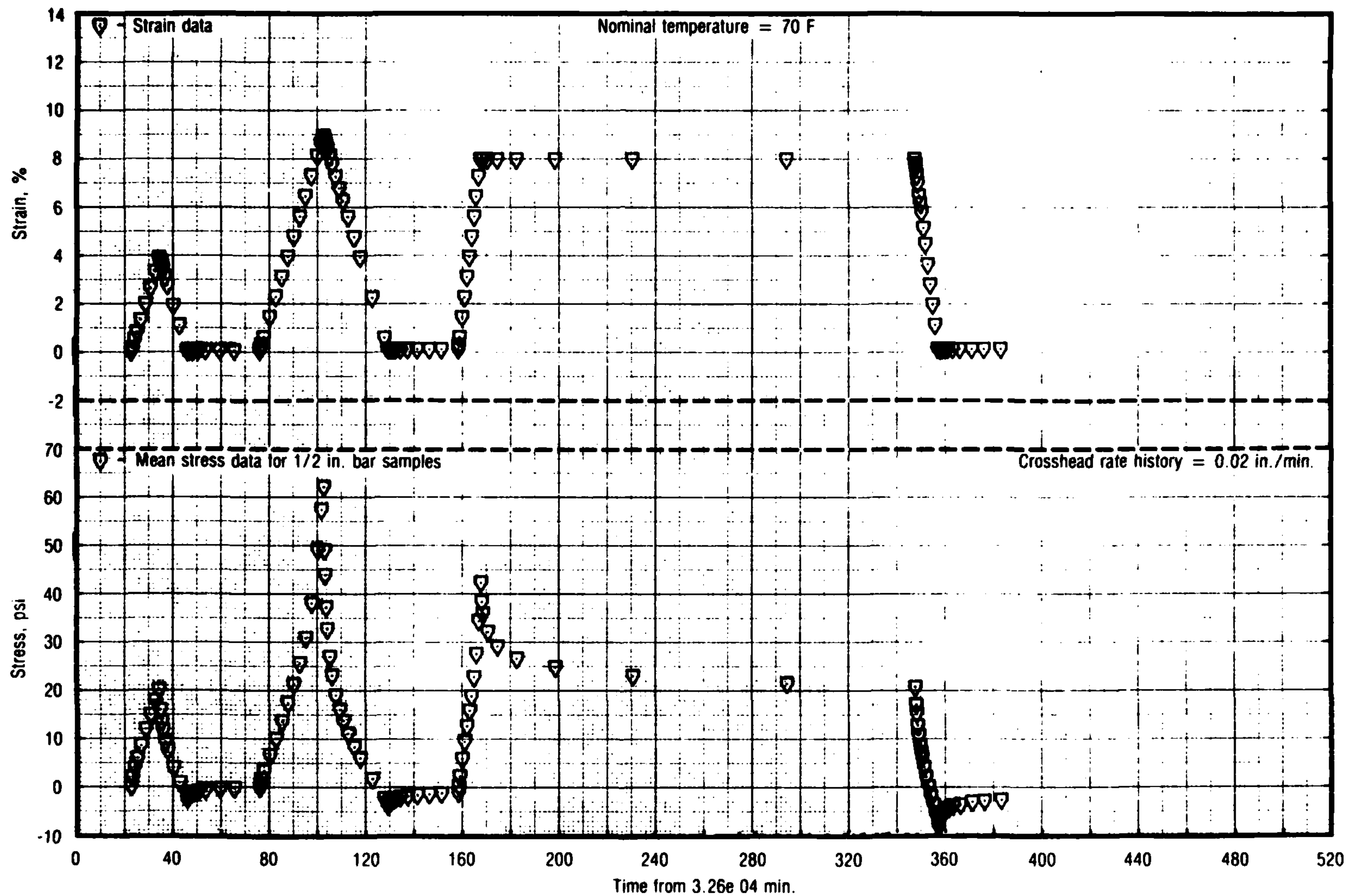


Figure 31. Test No. 11, Part 2 - Stress While Cycling for UTP-3001-750/7768

28760

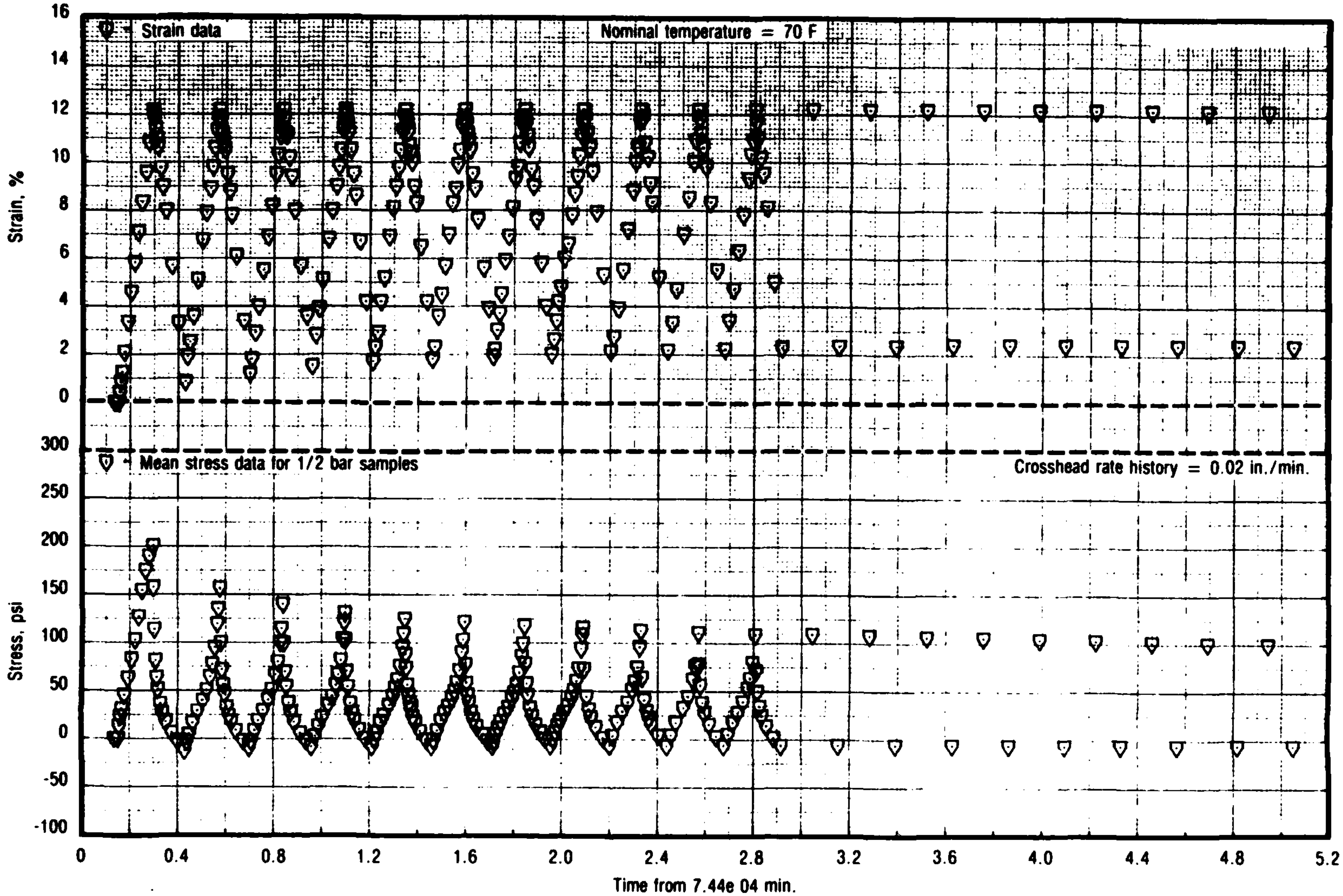


Figure 32. Test No. 11, Part 2 - Stress While Cycling for UTP-3001-750/7768
28761

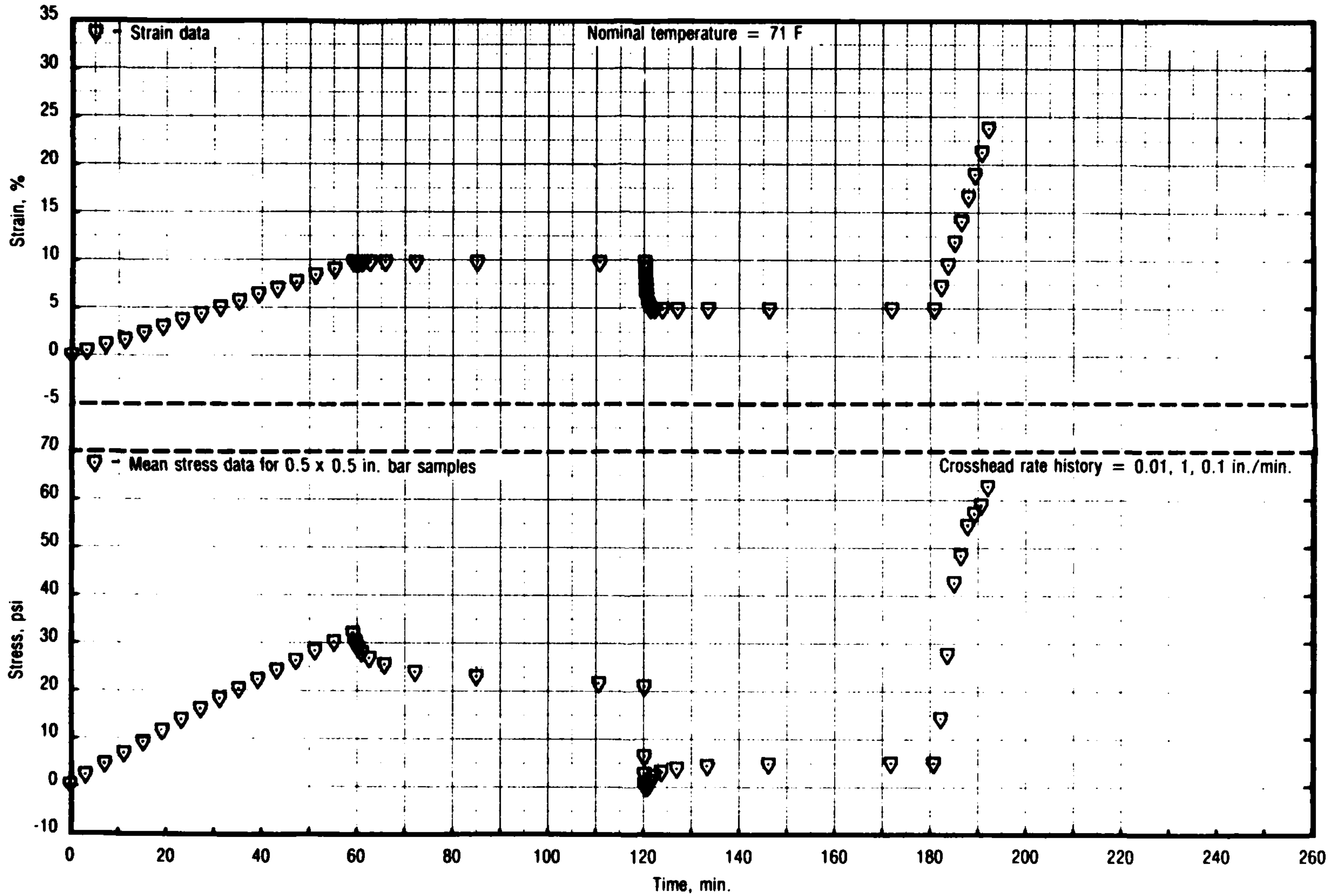


Figure 33. Test No. 12 - Stress While Step Straining for UTP-19,360B-400/1777

28762

TABLE 20. TEST NO. 12 - 1/2-IN. BAR STRESS WHILE STEP STRAINING (SHEET 1 OF 2)

PROPELLANT: UTP 19360B 400/1777
REQUESTOR: Carlton
WOR:

DATE: 6/16/81
OPERATOR: JWD

DEFINITIONS:
- Time = Time From Start of Test (min)
- σ = Stress (psi)
- ε = Strain (%)
- T(air) = Test Air Temperature (F)
- T(prop) = Test Propellant Temperature (F)

RELATIONSHIPS:
- σ = Force/Area
- ε = Sample Extension/Length

NOMINAL VALUES:
- Test Temp = 71 F
- Gage Length = 6.00 in
- Nom. Strain = 10.5,Failure %
- XHD Rate = .01,1,.1 in/min

CALIBRATION DATA:

		Sample 1	Sample 2	Sample 3
Cal Wt = 5.0 lbs				
Load Cal	(lbs/volts)	5.856	6.105	6.120
Offset	(volts)	0.029	-0.006	0.075
Pot Cal	(in/volts) =	-0.386		
Temp	(F) =	71.0		

	1	2	3
AREAS (sq in):	0.250	0.249	0.249

STRESS DATA (psi):

SET	Time	T(prop)	T(air)	Strain	Sample 1	Sample 2	Sample 3	Avg	St Dev
1	0.00000	73.6	72.6	0.00	0.26	0.23	0.25	0.25	0.011
2	3.22987	73.6	72.6	0.50	2.69	2.19	2.34	2.41	0.178
3	7.23012	73.1	73.1	1.18	5.34	4.15	4.62	4.71	0.425
4	11.23050	73.9	73.0	1.68	7.97	6.01	6.91	6.96	0.696
5	15.23028	75.1	72.8	2.40	10.60	7.89	9.26	9.25	0.958
6	19.23060	72.7	72.3	3.06	13.30	9.80	11.71	11.61	1.239
7	23.22992	72.4	71.8	3.73	15.96	11.70	14.12	13.92	1.511
8	27.23065	74.6	72.4	4.38	18.51	13.52	16.43	16.15	1.770
9	31.23004	75.2	73.0	5.06	20.95	15.29	18.61	18.28	2.010
10	35.23024	73.3	72.9	5.70	23.24	17.00	20.70	20.31	2.222
11	39.23019	72.8	73.1	6.42	25.50	18.70	22.78	22.33	2.421
12	43.23039	72.6	73.3	7.00	27.61	20.39	24.80	24.26	2.575
13	47.23063	73.4	72.8	7.69	29.80	22.17	26.92	26.30	2.725
14	51.23015	73.5	72.1	8.40	31.92	23.97	29.03	28.31	2.846
15	55.23027	73.7	72.0	9.02	33.89	25.68	30.95	30.17	2.944
16	59.15388			9.70	35.83	27.35	32.84	32.00	3.039
17	59.20560	72.9	72.4	9.70	35.62	27.16	32.59	31.79	3.031
18	59.61435	73.0	72.8	9.71	33.81	25.88	30.88	30.19	2.836
19	59.81462	72.8	73.1	9.69	33.24	25.47	30.34	29.68	2.778
20	60.21521	72.5	72.7	9.70	32.35	24.80	29.48	28.88	2.693
21	61.01553	73.1	72.9	9.70	31.28	24.02	28.47	27.92	2.588
22	62.61616	72.4	73.0	9.72	30.02	23.07	27.22	26.77	2.472
23	65.81652	73.8	72.9	9.71	28.54	21.89	25.76	25.39	2.362
24	72.21747	74.2	73.1	9.70	26.82	20.58	24.17	23.86	2.215
25	85.01775	73.0	72.5	9.73	25.79	19.72	23.41	22.97	2.160
26	110.61869	73.1	72.4	9.70	24.18	18.45	21.95	21.53	2.041

TABLE 20. TEST NO. 12 - 1/2-IN. BAR STRESS WHILE STEP STRAINING
(SHEET 2 OF 2)

27	120.07475	72.9	72.7	9.70	23.54	17.92	21.15	20.87	1.995
28	120.13984			9.70	23.54	17.91	21.14	20.86	1.995
29	120.17741			9.05	7.50	5.58	5.69	6.26	0.761
30	120.21536			8.43	3.42	2.25	2.12	2.60	0.505
31	120.25243			7.81	1.04	0.25	0.06	0.45	0.365
32	120.29037			7.28	0.00	0.00	0.00	0.00	0.000
33	120.32740			6.90	0.00	0.00	0.00	0.00	0.000
34	120.36539			6.58	0.00	0.00	0.00	0.00	0.000
35	120.40255			6.34	0.00	0.00	0.00	0.00	0.000
36	120.42240			6.22	0.00	0.00	0.00	0.00	0.000
37	120.43982			6.14	0.00	0.00	0.00	0.00	0.000
38	120.75186	72.8	73.1	5.33	0.00	0.00	0.00	0.00	0.000
39	120.95217	74.9	72.8	5.08	0.09	0.00	0.00	0.03	0.037
40	121.35280	73.8	73.3	4.83	1.61	0.71	0.77	1.03	0.355
41	122.15353	73.1	72.8	4.82	2.76	1.76	1.98	2.17	0.370
42	123.75396	73.5	73.6	4.82	3.65	2.58	2.89	3.04	0.390
43	126.95477	74.3	73.6	4.81	4.39	3.22	3.59	3.73	0.422
44	133.35560	74.0	73.0	4.80	4.96	3.73	4.15	4.28	0.441
45	146.15656	75.0	73.2	4.81	5.36	4.07	4.50	4.65	0.465
46	171.75738	73.6	73.3	4.81	5.46	4.26	4.70	4.81	0.429
47	180.67706	75.4	73.6	4.80	5.50	4.26	4.71	4.82	0.445
48	180.74794			4.80	5.50	4.26	4.71	4.82	0.445
49	182.14869	73.5	73.5	7.17	15.75	12.51	14.13	14.13	1.146
50	183.54835	73.4	73.1	9.43	30.61	23.95	28.04	27.53	2.375
51	184.94795	74.7	73.0	11.79	46.99	37.09	43.39	42.49	3.541
52	186.34851	74.4	73.0	13.98	52.64	42.76	49.10	48.17	3.542
53	187.74818	73.6	73.3	16.52	56.24		52.66	54.45	2.533
54	189.14839	73.0	72.9	18.86	58.89		55.05	56.97	2.719
55	190.54867	72.4	72.9	21.18	60.96		56.49	58.72	3.161
56	191.94865	73.2	72.8	23.66	62.59			62.59	0.000

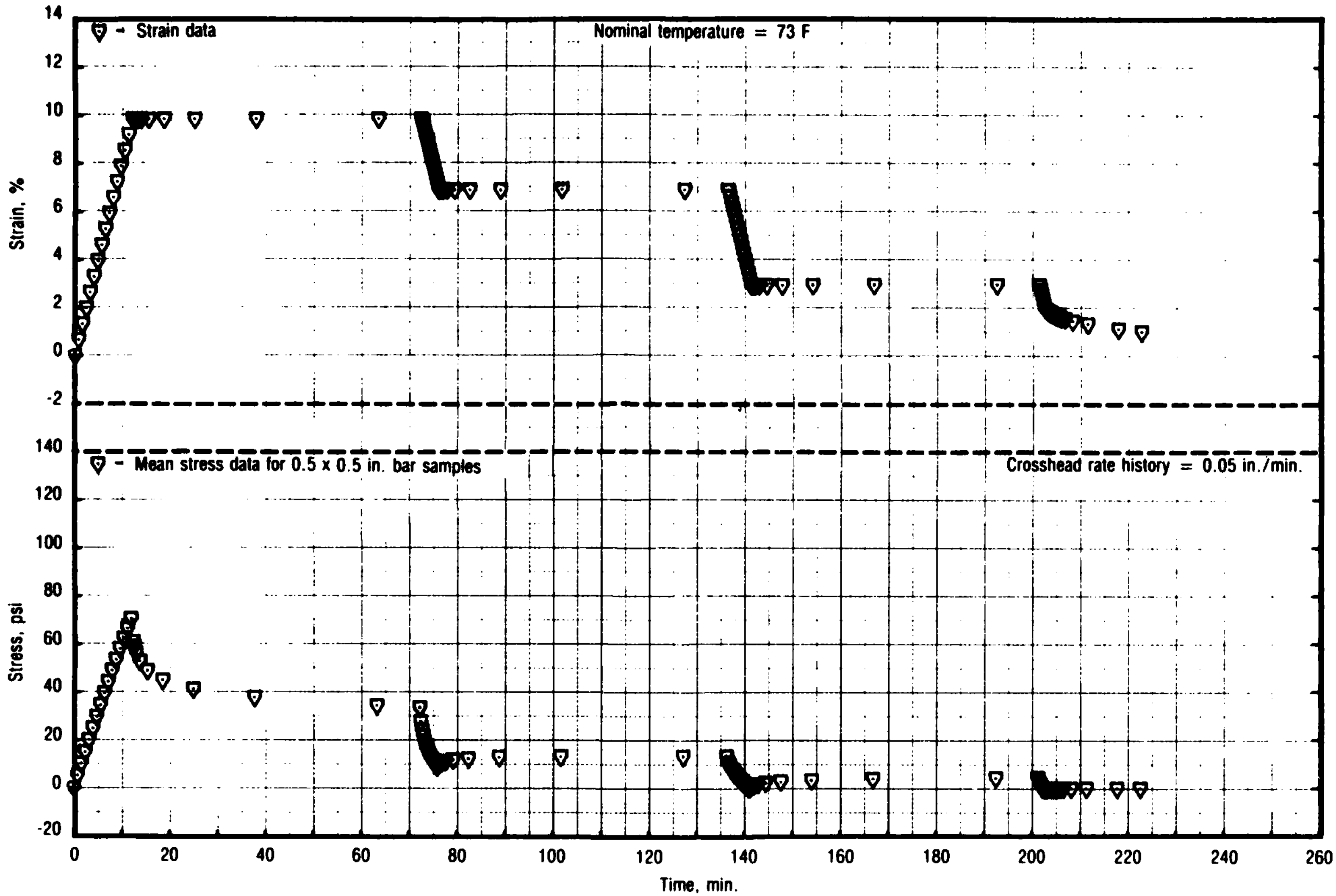


Figure 34. Test No. 13 - Stress While Step Straining for UTP-3001-750/7768

28763

TABLE 21. TEST NO. 13 - 1/2-IN. BAR STRESS WHILE STEP STRAINING (SHEET 1 OF 3)

PROPELLANT: UTP 3001 750/7768
REQUESTOR: Carlton
WOR:

DATE: 6/5/81
OPERATOR: JWD

DEFINITIONS:
- Time = Time From Start of Test (min)
- σ = Stress (psi)
- ε = Strain (%)
- T(air) = Test Air Temperature (F)
- T(prop) = Test Propellant Temperature (F)

RELATIONSHIPS:
- σ = Force/Area
- ε = Sample Extension/Length

NOMINAL VALUES:
- Test Temp = 73 F
- Gage Length = 6.00 in
- Nom. Strain = 10,7,3,0 %
- XHD Rate = .05 in/min

CALIBRATION DATA:

		Sample 1	Sample 2	Sample 3
Cal Wt =	5.0 lbs			
Load Cal	(lbs/volts)	5.959	7.421	6.156
Offset	(volts)	0.007	0.010	-0.005
Pot Cal	(in/volts) =	-0.387		
Temp	(F) =	75.1		

AREAS (sq in): 0.249 0.249 0.249

STRESS DATA (psi):

SET	Time	T(prop)	T(air)	Strain	Sample 1	Sample 2	Sample 3	Avg	St Dev
1	0.01761	75.7	102.7	0.01	0.11	0.26	0.20	0.19	0.052
2	0.81787	75.9	73.9	0.68	4.81	6.84	4.74	5.47	0.845
3	1.61787	75.9	73.9	1.34	9.54	11.83	10.07	10.48	0.848
4	2.41813	75.1	74.3	2.00	13.73	16.72	14.98	15.14	1.064
5	3.21822	75.4	74.4	2.65	18.40	22.22	19.90	20.17	1.360
6	4.01789	74.9	74.8	3.31	22.79	27.70	24.60	25.06	1.752
7	4.81763	74.9	74.8	3.97	27.01	33.20	29.42	29.88	2.204
8	5.61796	74.8	75.1	4.63	31.38	38.67	34.11	34.72	2.605
9	6.41771	75.0	75.3	5.28	35.65	44.16	38.91	39.57	3.035
10	7.21794	74.8	75.2	5.94	39.84	49.54	43.49	44.29	3.466
11	8.01760	75.3	75.5	6.60	44.03	54.87	48.06	48.99	3.875
12	8.81809	74.9	75.2	7.26	48.01	60.06	52.43	53.50	4.311
13	9.61028	75.0	75.4	7.91	52.19	65.15	56.84	58.06	4.643
14	10.41815	75.3	75.3	8.55	56.05	70.11	60.92	62.36	5.047
15	11.21707	74.7	75.4	9.21	59.86	74.84	64.86	66.52	5.392
16	12.00590			9.05	63.61	79.50	68.73	70.61	5.733
17	12.36862	75.0	75.4	9.06.	55.31	68.26	59.43	61.00	4.678
18	12.56892	75.1	75.5	9.86	53.53	65.87	57.48	58.96	4.458
19	12.96924	74.9	75.6	9.85	51.12	62.63	54.82	56.19	4.153
20	13.77011	75.0	75.7	9.86	48.03	58.63	51.46	52.71	3.826
21	15.37092	75.2	76.0	9.86	44.69	54.06	47.85	48.87	3.370
22	18.57127	75.7	76.2	9.85	41.12	49.43	44.00	44.85	2.983
23	24.97180	75.1	75.2	9.85	37.87	45.16	40.44	41.15	2.614
24	37.77218	74.8	75.4	9.85	34.84	41.17	37.15	37.72	2.265
25	63.37245	74.6	75.3	9.85	31.90	37.33	33.80	34.34	1.947
26	72.20479	75.0	76.1	9.85	31.07	36.19	33.04	33.43	1.825

TABLE 21. TEST NO. 13 - 1/2-IN. BAR STRESS WHILE STEP STRAINING
(SHEET 2 OF 3)

27	72.33300			9.85	31.06	36.18	33.03	33.43	1.824
28	72.52480	75.1	75.8	9.69	26.01	29.46	27.37	27.61	1.226
29	72.76473	75.2	76.1	9.49	22.96	25.46	24.06	24.16	0.887
30	73.00516	75.2	75.3	9.30	20.69	22.55	21.60	21.61	0.658
31	73.24519	75.5	75.8	9.10	18.95	20.25	19.75	19.65	0.465
32	73.48513	75.2	76.0	8.90	17.50	18.35	18.19	18.01	0.317
33	73.72492	75.4	76.0	8.71	16.01	16.76	16.79	16.52	0.313
34	73.96503	75.3	75.7	8.51	15.16	15.37	15.72	15.42	0.199
35	74.20469	75.3	75.6	8.32	14.20	14.20	14.73	14.38	0.215
36	74.44466	75.4	75.7	8.12	13.31	13.02	13.78	13.37	0.271
37	74.68468	75.4	75.5	7.92	12.51	12.08	12.93	12.51	0.301
38	74.92503	75.3	75.8	7.73	11.71	11.15	12.08	11.65	0.333
39	75.16543	75.3	75.9	7.53	11.03	10.38	11.38	10.93	0.358
40	75.40542	75.2	75.6	7.33	10.35	9.65	10.69	10.23	0.377
41	75.64492	75.4	75.7	7.14	9.75	9.15	10.05	9.65	0.322
42	75.88502	75.3	75.6	6.94	9.00	8.78	9.38	9.05	0.213
43	75.94500			6.89	8.81	8.68	9.21	8.90	0.193
44	76.24224	75.2	75.5	6.89	10.05	9.91	10.38	10.11	0.172
45	76.44293	75.7	75.6	6.89	10.32	10.26	10.64	10.41	0.142
46	76.84389	75.7	75.7	6.89	10.71	10.72	11.03	10.82	0.129
47	77.64412	75.2	75.1	6.89	11.17	11.27	11.44	11.29	0.099
48	79.24456	75.3	75.2	6.89	11.69	11.88	12.00	11.86	0.110
49	82.44505	74.9	74.6	6.89	11.98	12.55	12.45	12.32	0.216
50	88.84535	75.0	74.8	6.89	12.63	12.98	13.11	12.91	0.179
51	101.64602	75.2	76.2	6.89	12.70	13.33	13.36	13.13	0.264
52	127.24666	75.5	76.1	6.89	13.05	13.56	13.56	13.39	0.209
53	136.29471	75.3	75.3	6.87	12.91	13.05	13.57	13.18	0.249
54	136.36636			6.87	12.90	13.05	13.57	13.18	0.250
55	136.68631	75.1	75.5	6.61	10.48	9.97	10.93	10.46	0.340
56	137.00639	75.4	75.6	6.35	9.24	8.61	9.48	9.11	0.317
57	137.32643	75.5	75.1	6.09	8.13	7.71	8.32	8.05	0.218
58	137.64650	75.2	75.1	5.82	7.17	7.14	7.33	7.21	0.071
59	137.96651	75.3	74.9	5.56	6.31	6.65	6.44	6.47	0.122
60	138.28668	75.7	75.3	5.29	5.53	6.01	5.65	5.73	0.177
61	138.60689	75.2	75.0	5.02	4.71	5.22	4.90	4.95	0.183
62	138.92674	75.7	74.6	4.76	4.09	4.38	4.16	4.21	0.106
63	139.24638	75.2	74.9	4.49	3.42	3.57	3.47	3.49	0.054
64	139.56622	75.2	75.1	4.23	2.76	2.80	2.79	2.78	0.016
65	139.88706	75.5	75.0	3.96	1.99	2.06	2.15	2.07	0.059
66	140.20667	75.1	75.0	3.70	1.47	1.31	1.51	1.43	0.074
67	140.52654	75.3	74.7	3.43	0.92	0.62	0.89	0.81	0.120
68	140.84680	75.2	74.7	3.17	0.34	0.00	0.36	0.23	0.144
69	141.14540			2.92	0.00	0.00	0.00	0.00	0.000
70	141.43702	74.9	74.8	2.93	0.69	0.41	0.71	0.60	0.116
71	141.63762	75.4	74.4	2.93	0.86	0.65	0.99	0.83	0.119
72	142.03828	75.7	74.2	2.92	1.33	1.08	1.36	1.26	0.110
73	142.83916	75.2	75.0	2.92	1.76	1.62	1.81	1.73	0.070
74	144.43967	75.4	75.0	2.92	2.25	2.19	2.33	2.26	0.050
75	147.64018	75.0	75.6	2.92	2.76	2.82	2.87	2.82	0.040
76	154.04089	75.5	76.0	2.93	3.10	3.41	3.38	3.29	0.121
77	166.84116	75.2	74.9	2.93	3.80	4.04	3.91	3.92	0.087
78	192.44150	76.0	75.2	2.93	4.14	4.47	4.27	4.29	0.120
79	201.16797	75.1	75.5	2.93	4.19	4.60	4.38	4.39	0.143
80	201.23595	75.0	74.9	2.93	4.17	4.50	4.28	4.32	0.119
81	201.25200			2.93	4.17	4.48	4.25	4.30	0.114
82	201.47618	75.5	75.3	2.74	2.63	2.59	2.65	2.62	0.023
83	201.71641	74.9	75.4	2.54	1.67	1.39	1.66	1.57	0.113
84	201.95632	75.4	76.1	2.34	0.80	0.40	0.85	0.68	0.173

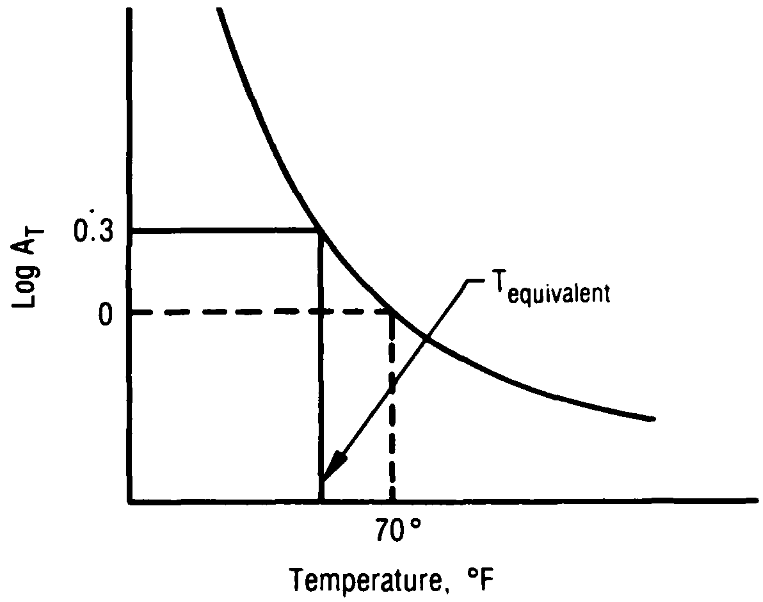
TABLE 21. TEST NO. 13 - 1/2-IN. BAR STRESS WHILE STEP STRAINING
(SHEET 3 OF 3)

85	202.19666	75.0	75.4	2.14	0.24	0.00	0.28	0.18	0.109
86	202.43640	75.5	75.5	1.94	0.00	0.00	0.00	0.00	0.000
87	202.67644	74.8	75.7	1.91	0.00	0.00	0.00	0.00	0.000
88	202.91607	75.2	75.7	1.87	0.00	0.00	0.00	0.00	0.000
89	203.15642	74.8	75.9	1.83	0.00	0.00	0.00	0.00	0.000
90	203.39620	75.9	76.2	1.81	0.00	0.00	0.00	0.00	0.000
91	203.63620	75.0	75.9	1.77	0.00	0.00	0.00	0.00	0.000
92	203.87648	75.5	76.0	1.75	0.00	0.00	0.00	0.00	0.000
93	204.11677	74.9	75.9	1.73	0.00	0.00	0.00	0.00	0.000
94	204.35603	75.3	75.9	1.70	0.00	0.00	0.00	0.00	0.000
95	204.59645	75.1	75.9	1.68	0.00	0.00	0.00	0.00	0.000
96	204.79200			1.65	0.00	0.00	0.00	0.00	0.000
97	205.09971	76.1	75.9	1.63	0.00	0.00	0.00	0.00	0.000
98	205.30022	75.5	75.9	1.61	0.00	0.00	0.00	0.00	0.000
99	205.70089	75.4	77.4	1.56	0.00	0.00	0.00	0.00	0.000
100	206.50127	75.5	76.3	1.53	0.00	0.00	0.00	0.00	0.000
101	208.10157	76.2	76.4	1.43	0.00	0.00	0.00	0.00	0.000
102	211.30182	75.5	76.4	1.31	0.00	0.00	0.00	0.00	0.000
103	217.70209	75.8	76.2	1.10	0.00	0.00	0.00	0.00	0.000
104	222.54589	75.5	75.9	0.98	0.00	0.00	0.00	0.00	0.000

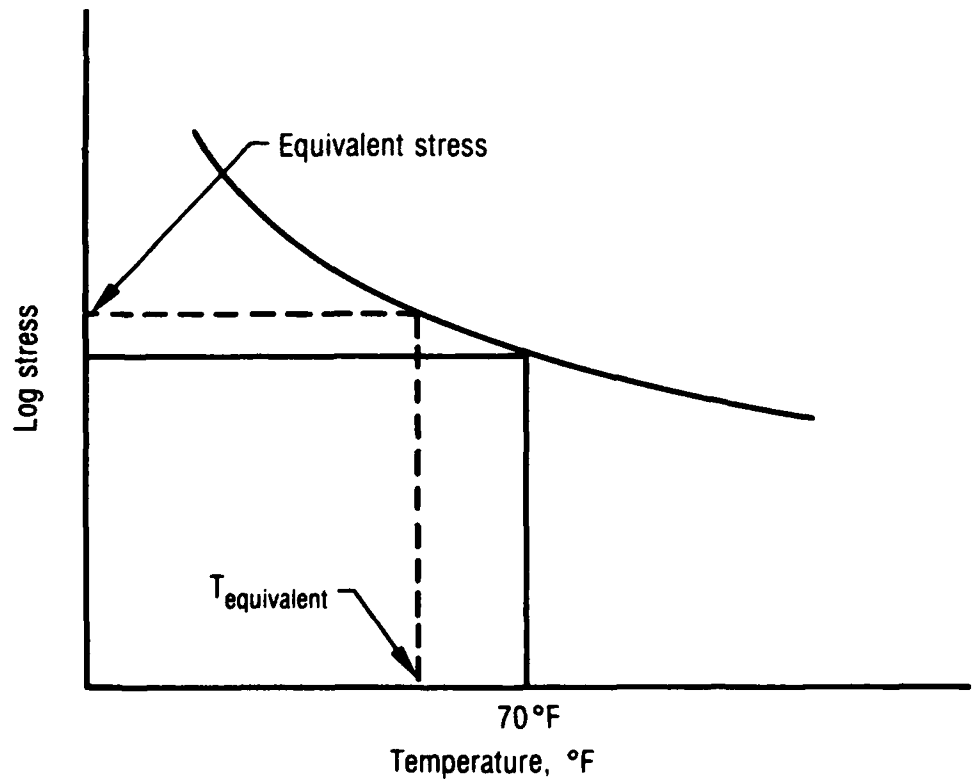
3.1.14 Propellant Aging Effects During Phase II Testing

The numerous and complex tests involved in the uniaxial-isothermal evaluation of the two propellants (UTP-3001 and UTP-19,360B) covered an approximate 3-month time period. Since the 6-in. bar specimens at constant rate (test No. 1) were run first, they were used as the standard to compare the balance of the data.

Stress-strain plots of UTP-3001, test No. 1 are shown in Figures 35, 36, and 37 for 41, 75, and 124°F tests, respectively. Crosshead rates of 10, 1, and 0.1 in./min. are shown for each temperature with the ambient tests down to 0.001 in./min. The same data are shown in Figures 38, 39, and 40 for UTP-19,360B. Comparison of the other tests was based on the initial ramp loading or undamaged state. Test No. 6 was a full, one-half and one-quarter load creep test with crosshead loading rate of 1 in./min. The peak stress-strain points, when the crosshead stopped, were compared to the constant rate plots as shown in Figure 35, etc. All the data are given in Tables 22 and 23 for UTP-3001 and UTP-19,360B, respectively. When crosshead rates did not match, a time-temperature equivalent stress value was selected for comparison purposes. These data were considered approximate. Stress values that were considered reliable (i.e., very close) were marked in the tables with a single approximate sign (~) while those that left some doubt due to the shift were marked with a double approximate (≈). Some tests were run at 5 in./min. rather than the 10 in./min. comparison data. The 10 in./min. equivalent of the 5 in./min. data can be determined from the rate shift (i.e., $\log A_T = \log 10/5 = 0.30$). The WLF curve (in text figure) is used to pick off the equivalent temperature. The high rate stress value being sought is equivalent to a lower temperature at the lower rate (5 in./min.).



The equivalent temperature is then used to obtain the equivalent stress value from a stress-temperature plot (in text Figure).



The stress-temperature plot can also be used to obtain equivalent stress values when the temperatures do not match at the same rate.

After the initial ramp loading, the propellant was considered damaged. In most instances the tests were of short enough duration to neglect any aging effect during test. Since bulk storage at controlled ambient conditions has not shown a significant aging effect over 3 months, this was also neglected. Rather it was lumped into the between carton difference. The sample handling procedure established was to machine one carton at a time, hold all samples overnight in a nitrogen flushed dry box (≤10% RH) before testing, and then test all samples from the dry box before machining additional specimens. The data in Table 22 for UTP-3001 indicate little difference between boxes 1 and 2 but a one-third higher average stress in box 3. The other significant change was within a box due to the amount of storage time in the dry box. During the 13 days the residual of box 2 was in the dry box, the stress changed from 30% below the mean to 10% above the mean. The UTP-3001 tests from box 3 have been replaced with another carton which was sample tested before doing the program tests. This provided a reasonable assurance that the results would be of the same family as the original constant rate data (test No. 1). The data from UTP-19,360B in Table 23 do not show as much effect for dry box storage or between box differences compared to the UTP-3001 propellant.

Both propellants have indicated that dry box storage will increase the stress capability. This is assumed to be due to loss of moisture and it is reversible as is shown in Figure 41 for UTP-3001. In this example, specimens held in the dry box for 4 months were exposed to 58 and 85% relative humidity for 1 week. All six samples were tested simultaneously in a CSD multistation tester.

The one test which may need some special treatment is the Quinlan complex history No. 11 (see section 3.1.11). After 12 cycles and 2 relaxation periods, the samples were removed for 4 days storage in a dry box. They were then followed by (1) relaxation - 7 days in a dry box, (2) two cycles - a relaxation period - 2 weeks in a dry box, (3) two cycles - a relaxation period - 1 month in a dry box, and (4) cycling to failure. At this point it is not clear just how to separate the stress increase due to rehealing from the dehydration effect of

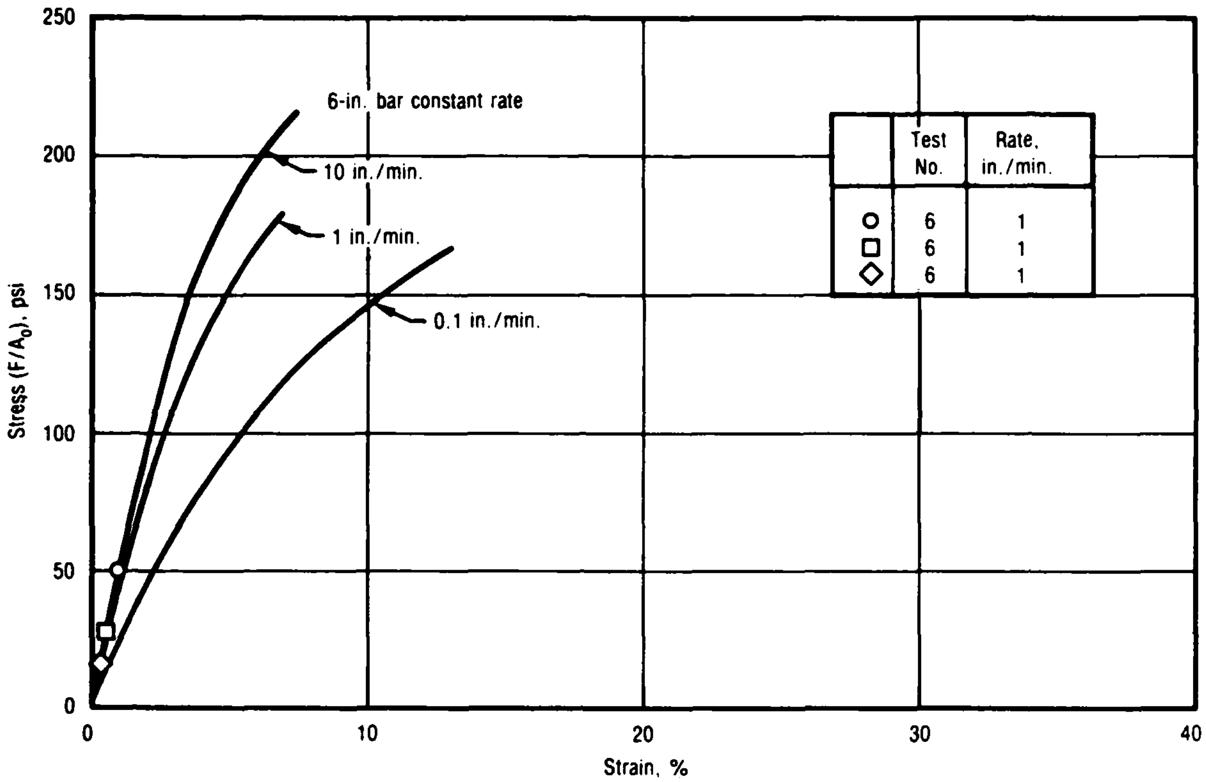


Figure 35. Initial Ramp for UTP-3001-750/7768 39°F Tests Compared to the 6-in. Bar Constant Rate Data

28769

the dry box particularly for the 1 month storage period. The test times at approximately 50% RH were too short to have any significant effect on propellant stress capability. Both propellants showed reasonable correspondence of the initial ramp to the reference constant rate data.

3.2 TWO-DIMENSIONAL AND VARIABLE TEMPERATURE INVESTIGATION

The biaxial and nonisothermal testing was conducted on specimens of UTP-3001 and UTP-19,360B propellants as detailed in Figure 42. The biaxial samples were cast into prelined redwood boxes with a 1.25-in. gage length by 6-in. wide and machined flat to a 0.25-in. thickness. The response properties rather than failure properties were of interest so the discontinuity at the redwood interface did not affect the desired behavior. The 1/2 x 1/2 x 6-in. specimens were used for straining-cooling and cyclic strain tests. Shear relaxation tests

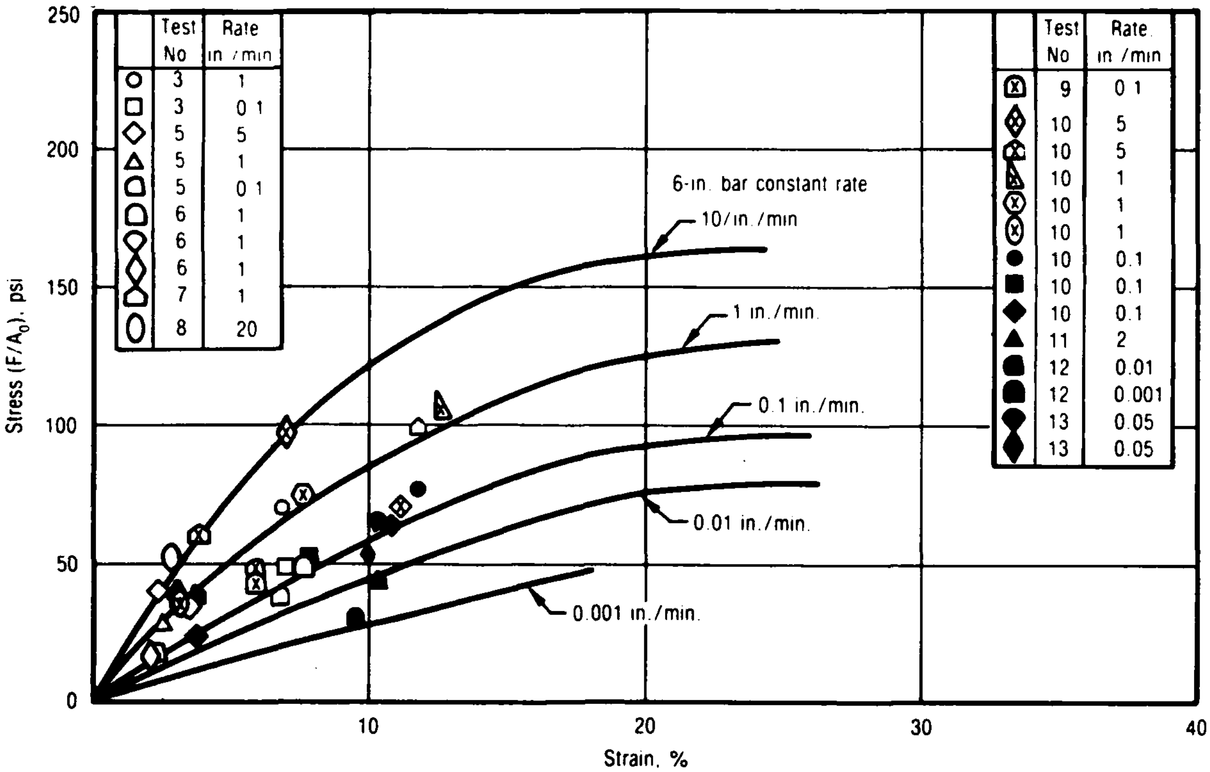


Figure 36. Initial Ramp for UTP-3001-750/7768 75°F Tests Compared to the 6-in. Bar Constant Rate Data

28766

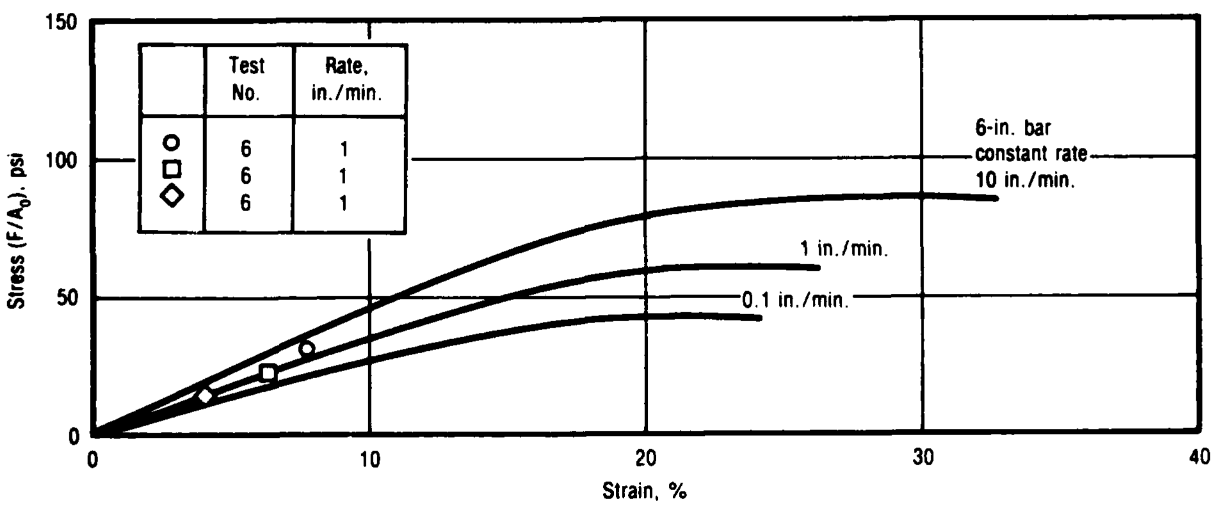


Figure 37. Initial Ramp for UTP-3001-750/7768 124°F Tests Compared to the 6-in. Bar Constant Rate Data

28768

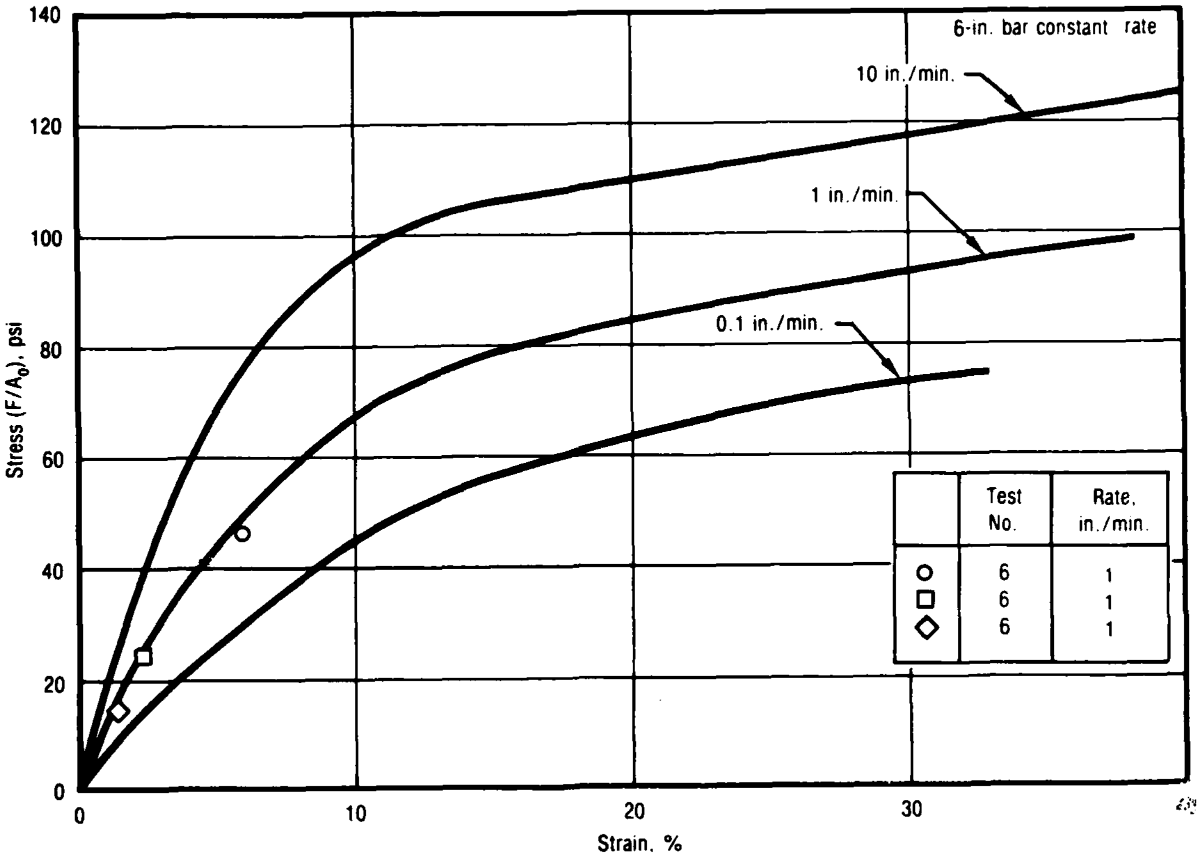


Figure 38. Initial Ramp for UTP-19,360B-40C/1777 40°F Tests Compared to the 6-in. Bar Constant Rate Data

28770

were run with 1 x 1 x 3-in. specimens bonded directly to steel anvils. Details are given in later sections. The equipment discussed in section 3.1 was utilized for this testing; however, only three biaxial specimens could be tested at once because of space limitations in the oven.

The biaxial specimens used in this part of the program were cast into redwood boxes similar to that shown in Figure 5. The space between redwood blocks was 1.25-in. instead of the 6-in. for the uniaxial bars. A mill finished specimen is shown in Figure 43. The propellant was left flat rather than necking it down as with standard JANNAF biaxial specimens. The gage length was designated at the wood to wood distance for strain evaluation. Response properties rather than failure properties were of interest so the boundary

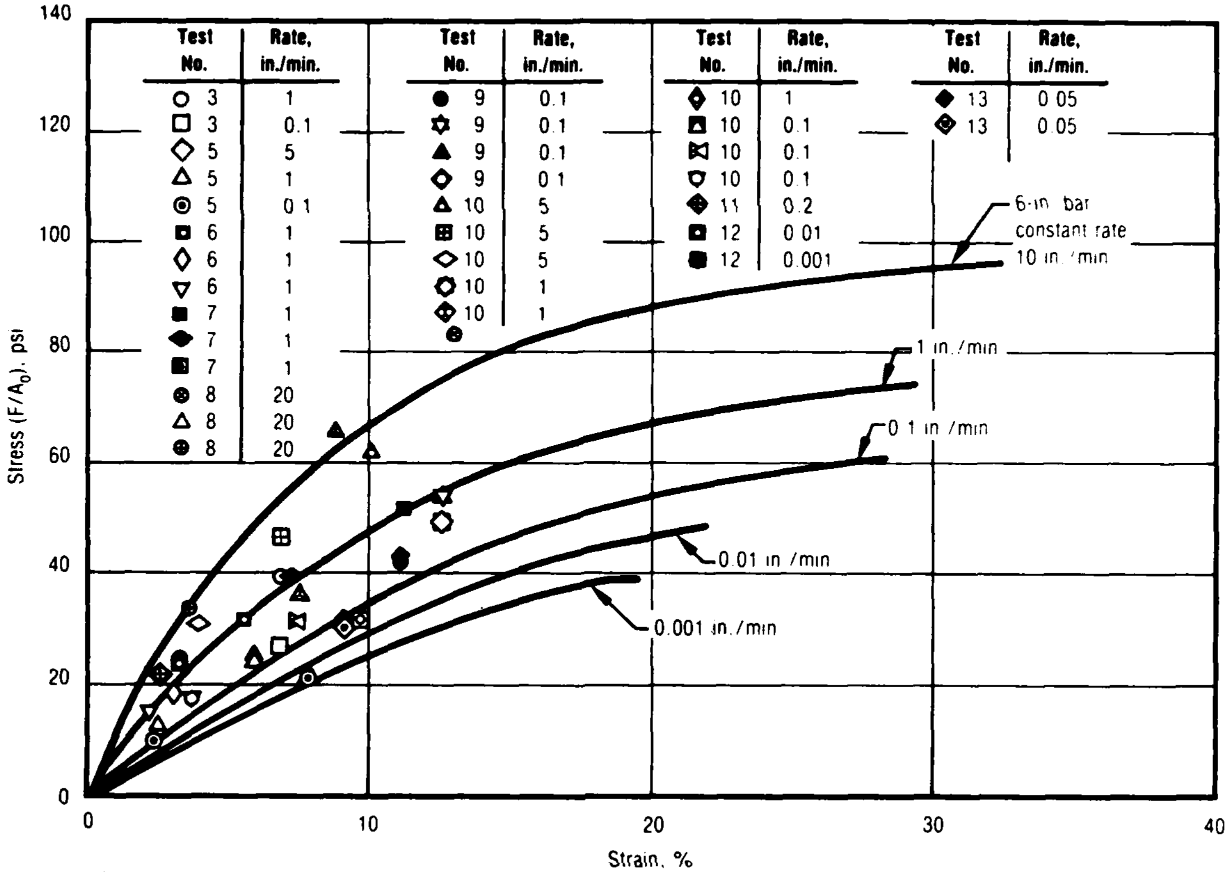


Figure 39. Initial Ramp for UTP-19,360B-400/1777 70°F Tests Compared to the 6-in. Bar Constant Rate Data

28771

perturbation was neglected. Some data taken from the literature(2) have been reproduced for evaluation of the stress-strain behavior across the biaxial field (see Figures 44 through 47).

The shear samples (Test No. 17) were 1 x 1 x 3-in. blocks of propellant that were bonded to the test fixture (shown in Figure 48) after being machined. The pull rods were attached to the offset plates so that the load was transmitted through the center of the sample as shown. Since strain was limited to 5% for the shear relaxation test, the sample was assumed to be in simple shear. The shear strain (γ) was calculated as the tangent of

Reference 2 - Jones, J., "Solid Propellant Structural Integrity Investigations: Dynamic Response and Failure Mechanisms in Solid Propellants," RPL-TDR-64-32, Vol. I, Lockheed Propulsion Co., February 1964.

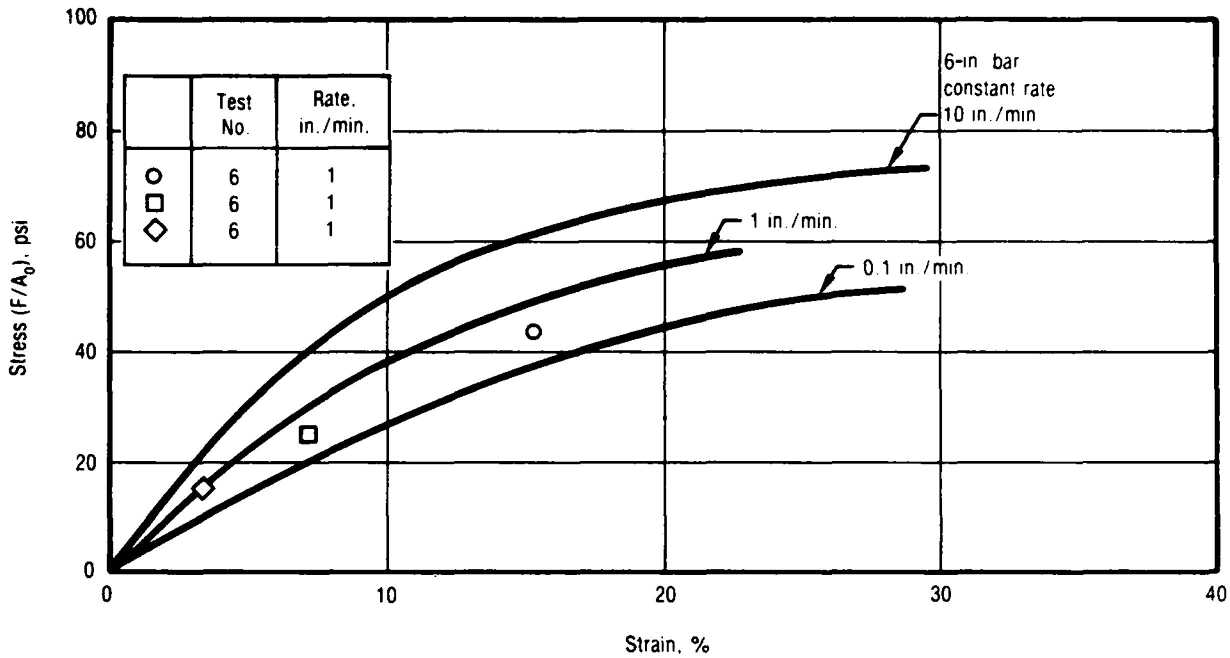


Figure 40. Initial Ramp for UTP-19,360B-400/1777 123°F Tests Compared to the 6-in. Bar Constant Rate Data

28772

the displacement angle or ΔL/G.L. The shear stress (τ) was calculated as force/area (area = 3 sq. in.).

The data modification to insert peak and minimum stress points previously discussed were utilized for the biaxial and nonisothermal tests.

3.2.1 Biaxial Constant Rate Test No. 14

The biaxial constant rate tests to failure were run with the 1/4 x 1-1/4 x 6-in. specimens of UTP-3001 and UTP-19,360B. The 40, 70, and 120°F tests were run at crosshead rates of 2, 0.2, and 0.2 in./min. The test equipment, with specimens in place, is shown in Figure 49. A typical load-time curve is shown in Figure 50 for UTP-19,360B at 71°F and 2 in./min. crosshead rate. Because of the fixtures and more difficulty in adjusting linkage than with the 6-in. bar specimens, the three samples did not start loading simultaneously. Sample 2 was adjusted to an effective zero and is shown in Figure 51. Tabular data are given in Table 24.

TABLE 22. STRESS-STRAIN COMPARISON FOR UTP-3001 TESTS
(SHEET 1 OF 2)

T8718

Test No.	Temperature, F	Rate, in./min.	Strain, %	Stress, psi	Stress, psi Test No. 1	Difference, %	Box No.	Days After Machining	Remarks
5	Ambient	5	2.40	40.66	~36	13	1	11	Mean
	Ambient	1	2.47	27.28	27.5	-1	1	15	+4.2%
	Ambient	0.1	2.36	16.70	16.5	1	1	15	
6	Ambient	1	5.94	47.8	57	-16	2	1	Box 2
	Ambient	1	3.54	33.62	37	-9	2	2	Box 2
	Ambient	1	1.55	17.17	18	-5	2	5	Mean
	120	1	6.29	22.40	22.5	-0.4	2	6	+1.1%
	120	1	4.02	15.3	15	2	2	6	over box 1
	120	1	7.71	30.1	27	11	2	7	
	40	1	1.00	50.0	50	0	2	7	
	40	1	0.48	25.8	24	8	2	8	
	40	1	0.35	15.2	15	1	2	8	
10	Ambient	5	6.94	96.1	~87	10	2	9	
	↓	5	3.78	59.8	~55	9	2	9	
	↓	1	12.55	106	98	8	2	9	
	↓	1	7.53	76.3	68.5	11	2	9	
	↓	1	3.29	36.7	35	5	2	12	
	↓	0.1	11.78	76.7	66.5	15	2	12	
	↓	0.1	7.83	52.0	47	11	2	12	
	↓	0.1	3.72	23.6	24	-2	2	12	
	Ambient								
3	Ambient	1	6.91	69.74	64	9	3	1	
	Ambient	0.1	6.93	47.73	42.5	12	3	1	
8	Ambient	20	3.05	56.7	~58	-22	4	2	

TABLE 22. STRESS-STRAIN COMPARISON FOR UTP-3001 TESTS
(SHEET 2 OF 2)

T8718

Test No.	Temperature, R	Rate in./min.	Strain %	Stress, psi	Stress, psi Test No. 1	Difference, %	Box No.	Days After Machining	Remarks
9	Ambient	0.1	6.63	41.8	41	1.9	4	2	
7	Ambient	1	12.08	98.9	96	3	4	2	
13	Ambient	.05	10.81	64.3	~56	14.7	4	4	
	Ambient	.05	10.08	56.2	~53	5.9	4	4	
12	Ambient	0.01	10.40	40.5	46	-12	4	3	
	Ambient	0.001	9.82	29.9	27	10.7	4	3	
11	Ambient	2	3.08	41.8	~36	-14	1	3	

Notes: 1. Box 1 used up 16 days after machining; test 5 mean = 4.2% over constant rates tests.
2. Box 2 used up in 13 days after machining; box 2 mean = 1.1% over box 1 constant rate but it changed from -30 to +10% during the 13 days.

TABLE 23. STRESS-STRAIN FOR UTP-19,360B TESTS
(SHEET 1 OF 2)

T8719

Test No.	Temperature, F	Rate, in./min.	Strain, %	Stress, psi	Stress, psi Test No. 1	Difference, %	Box No.	Days After Machining	Remarks
5	Ambient	5	2.49	21.8	~24	-9	1	11	Mean
	Ambient	1	2.47	12.89	17.5	-26	1	15	-8.0% below
	Ambient	0.1	2.36	10.54	9.5	11	1	15	test 1
6	Ambient	1	5.50	32.0	31.5	2	2	1	Box 2
	Ambient	1	3.08	18.05	20.5	-12		2	mean
	Ambient	1	2.24	14.76	16	-8		5	-2.7%
	120	1	15.29	43.57	49	-11		6	below box 1
	120	1	7.10	25.0	29.6	-16		6	
	120	1	3.48	14.35	15.5	-7		7	
	40	1	5.95	46.13	50	-8		7	
	40	1	2.22	24.26	24.5	-1		8	
	40	1	1.35	14.0	16	-12	2	8	
10	Ambient	5	6.94	46.5	~50	-7	2	9	
		5	3.78	30.8	~33	-7		9	
		1	12.55	49.7	54.5	-9		9	
		1	7.53	36.7	39	-6		9	
		1	3.29	24.1	21.6	12		12	
		0.1	11.06	41.8	38	10		12	
		0.1	7.38	31.2	27	16		12	
		0.1	3.72	17.2	15	15		12	
	Ambient	5	10.11	62.0	~62	0	2	12	
3	Ambient	1	7.00	39.57	37.5	6	3	1	Box 3
	Ambient	0.1	6.89	27.2	25.5	7	3	1	mean
									+7.6%
									above box 1
8	Ambient	20	13.04	85.1	~85	0	3	1	
	Ambient	20	8.46	66.7	~68	-2	3	2	
	Ambient	20	3.61	32.9	~40	-18	3	3	

TABLE 23. STRESS-STRAIN FOR UTP-19,360B TESTS
(SHEET 2 OF 2)

T8719

Test No.	Temperature, F	Rate, in./min.	Strain, %	Stress, psi	Stress, psi Test No. 1	Difference, %	Box No.	Days After Machining	Remarks
9	Ambient	0.1	11.07	41.4	37.7	10	3	10	
		0.1	12.53	43.3	41.2	5		13	
		0.1	5.95	24.8	22	13		14	
	Ambient	0.1	5.95	24.2	22	10	3	14	
7	Ambient	1	11.28	51.8	51.5	0	3	15	
	Ambient	1	7.09	38.5	37.5	3	3	15	
	Ambient	1	3.27	23.6	21.5	10	3	16	
13	Ambient	0.05	9.21	32.1	~ 31	4	3	16	
	Ambient	0.05	9.16	30.9	~ 30.5	1	3	20	
12	Ambient	0.01	9.68	31.8	28.5	12	3	26	
	Ambient	0.001	7.86	21.9	20	10	3	41	
11	Ambient	2	3.03	23.2	~21	10	1	3	

Note: All of these data appear to be the same family with a few exceptions. While the percentages are high the absolute differences are not that great. There is an indication of drift from low to high during testing with box 2.

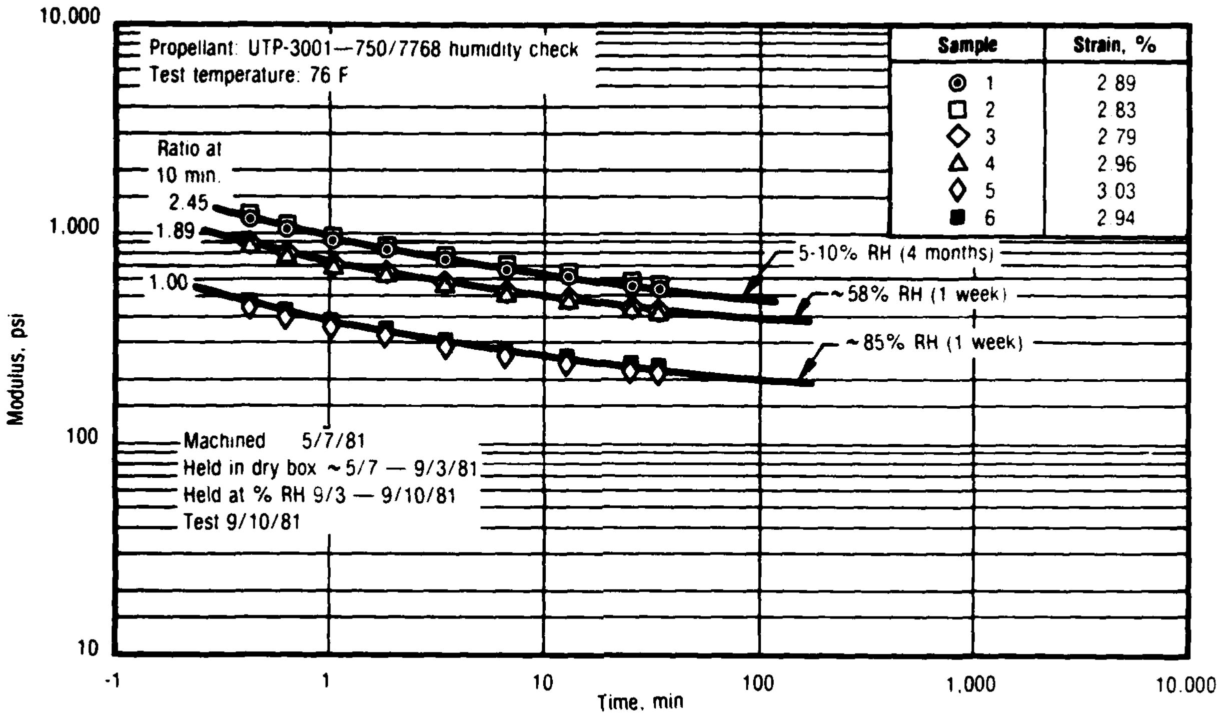


Figure 41. 1/2-in. Bar Stress Relaxation Data at 3% Nominal Strain

28773

3.2.2 Biaxial Straining-Cooling Test No. 15

Biaxial specimens of UTP-3001 and UTP-19,360B propellants were simultaneously strained and cooled from 115 to 40°F at a crosshead rate of approximately 3×10^{-5} in./min. over a 40-hr period. The results for UTP-3001 are shown in Figure 52. The stress-time traces for all three samples appear to start together but spread out as the test progresses. The tabular data are given in Table 25.

3.2.3 Biaxial Stress Relaxation Test No. 16

Biaxial stress relaxation tests were run with the 1/4 x 1-1/4 x 6-in. specimens of UTP-3001 and UTP-19,360B propellants at a nominal 3% strain and temperatures of 40, 70, and 120 F. The 40°F data for UTP-19,360B are shown in Figure 53 as typical with good reproducibility. The loading ramp rate was 0.2 in./min. Data are given in Table 26.

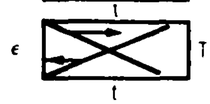
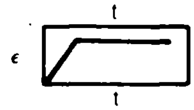
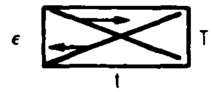
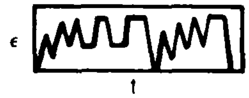
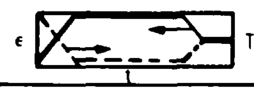
Test	Test Description	Damage Cycle/Test	Strain Cycle
14	Biaxial constant rate	Biaxial samples of UTP-3001 and UTP-19,360B were ramp loaded to failure at rates of 2, 0.2, and 0.02 in./min. at temperatures of 41, 70, and 120°F.	
15	Biaxial straining-cooling	Biaxial samples of UTP-3001 and UTP-19,360B were simultaneously strain and cooled from 120 to 40°F over a 40 hr. period.	
16	Biaxial relaxation	Biaxial samples of UTP-3001 and UTP-19,360B were run in stress relaxation tests at 40, 70, and 120°F.	
17	Shear relaxation	Shear samples of UTP-3001 and UTP-19,360B were run in stress relaxation tests at 70°F.	See above
18	6-in. bar straining- cooling	6-in. bars of UTP-3001 and UTP-19,360B were simultaneously strain and cooled from 120 to 40°F at three slow rates.	
19	Biaxial Quinlan complex history	Biaxial samples of UTP-3001 and UTP-19,360B were cycled for the Quinlan complex history test at 70°F.	
20	6-in. bar cyclic test	6-in. bars of UTP-3001 and UTP-19,360B were run in cyclic strain tests at 0.1 in./min. and 70°F.	
21	Biaxial thermal similitude	Biaxial samples of UTP-3001 and UTP-19,360B were run in ramp-relaxation-ramp tests with simultaneous cooling or heating (i.e., for reverse ramp)	See above plus last half thermal cycled 
	Note: Nominally three samples were run for each test and condition.		Legend: T = temperature t = time ε = strain

Figure 42. Biaxial and Nonisothermal Phase III Testing

28774

3.2.4 Shear Relaxation Test No. 17

Shear relaxation tests were run on 1 x 1 x 3-in. samples of UTP-3001 and UTP-19,360B propellants. The samples were post bonded to steel plates and run one at a time by loading them at 0.2 in./min and ambient temperature with offset fixtures so the load was transmitted through the center line of the sample. The 3 samples for each propellant were hand reduced and digitized for computer storage and printout. A typical example is shown for UTP-3001 in Figure 54 with data given in Table 27. Peak stresses and strain were very close as was the 1 hour relaxation stress on each propellant even though the samples were run separately.

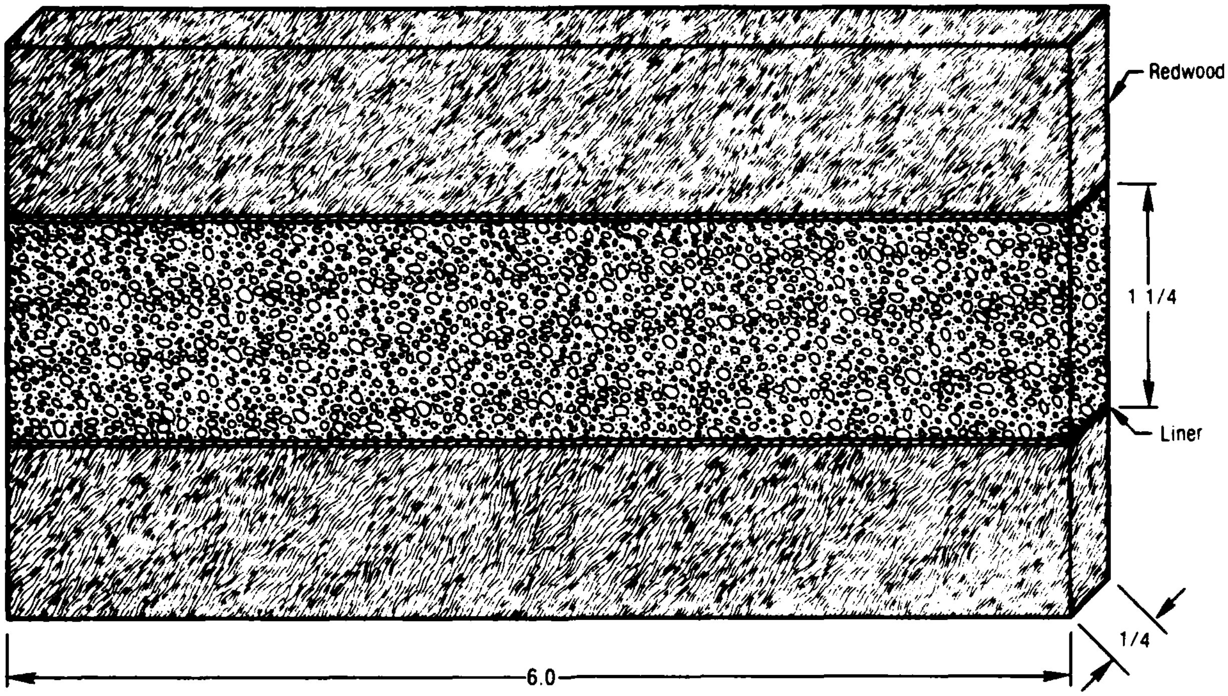


Figure 43. Finished Biaxial Specimen

28806

3.2.5 Straining-Cooling Multiple Rates Test No. 18

The rate effect on the straining-cooling response was determined on UTP-3001 and UTP-19,360B propellants. The 1/2 x 1/2 x 6-in. bar sample was used so that testing could be completed in the shortest time possible. The rate effect for the uniaxial specimens was then applied to the biaxial test No. 15. Cooling was from 110°F to 40°F at the crosshead rates of 0.002, 0.0002, and 0.0004 in./min. Typical data are shown for the 0.002 in./min. rate for UTP-3001 in Figure 55. Good reproducibility is shown within the set of 3 samples. Data are given in Table 28.

3.2.6 Biaxial Quinlan Complex History Test No. 19

The 1/4 x 1-1/4 x 6-in. biaxial samples of UTP-3001 and UTP-19,360B were subjected to the complex cycling and relaxation history indicated in Figure 42. When the tests were run the linkage, misalignment, etc. was such that the samples were not loaded an equivalent amount. The first sample to be loaded had the correct strain determined but strain on the other samples had to be adjusted to the time the stress ramp started on each. Each sample was reduced separately

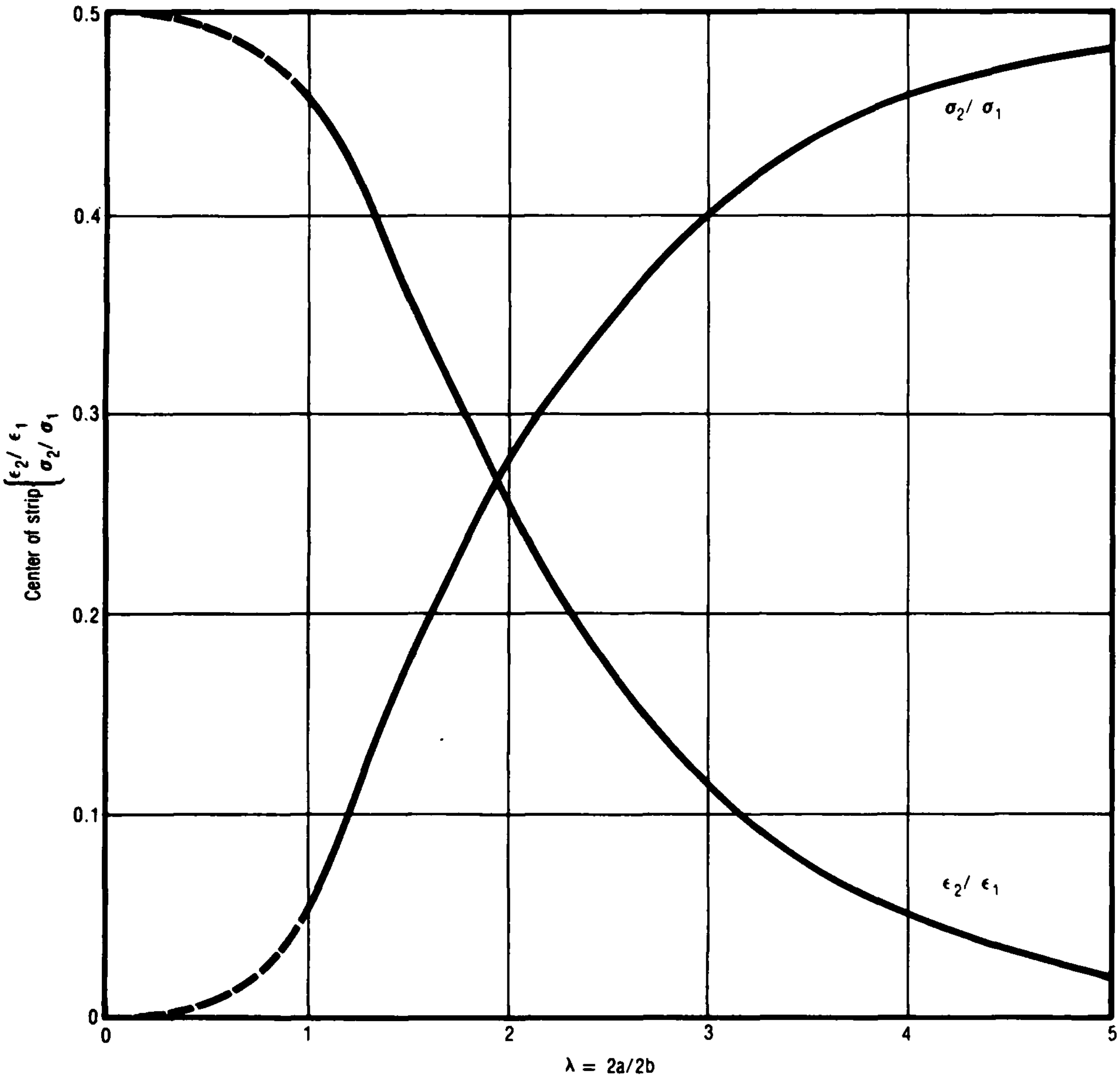


Figure 44. Principal Stress and Strain Ratios at the Center of Biaxial Strips for Varying Height-to-Width Ratios for a Poisson's Ratio of 1/2

28807

and data were modified to pick up the peak and minimum stress points. Sample 1 for UTP-3001 is shown in Figures 56 through 58 where the complex test has been divided into segments on an expanded time scale to show test details. The first cycle in Figure 56 showed no load and the second cycle showed very little. By contrast sample 3 (not included here) had a first peak stress-strain of 37 psi, 2.26% and second peak of 76 psi, 4.97%. During the unload part of the cycle

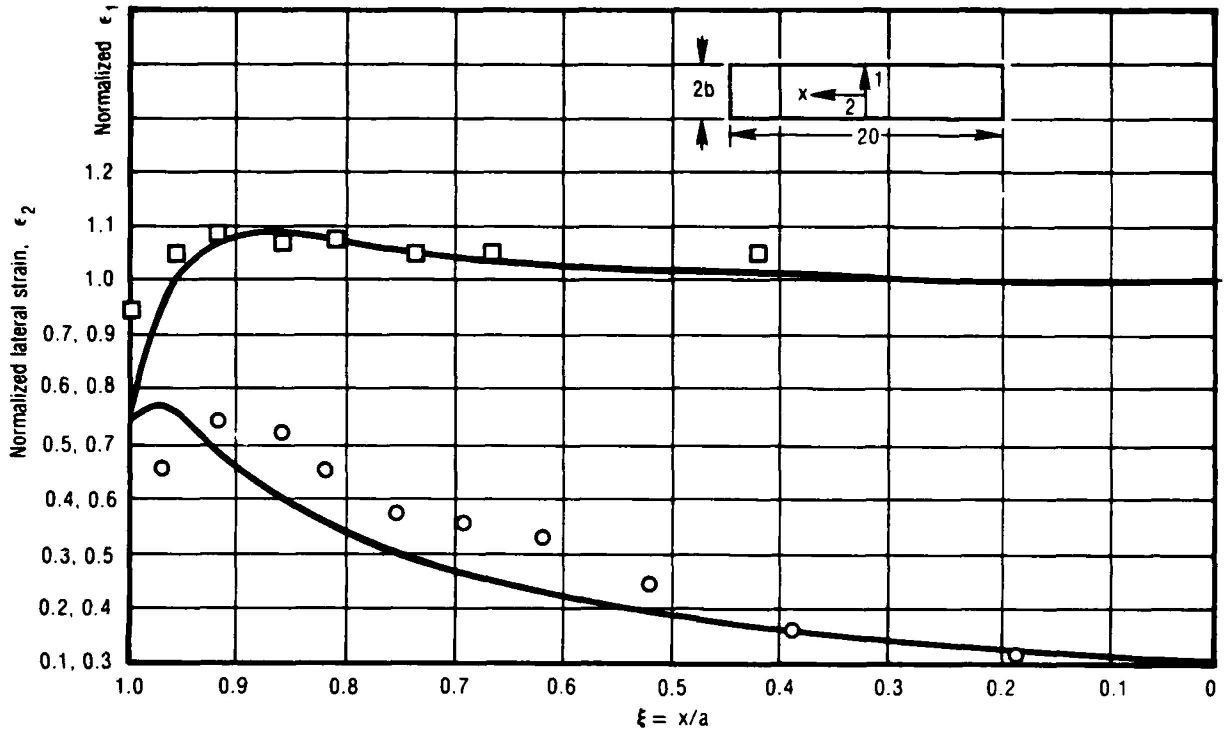


Figure 45. Normalized Axial and Lateral Strains Along the Midplane Biaxial Strip Specimen

28808

after stress reached zero, strain decay was estimated from other tests where strain was measured by cathetometer. Data are given in Table 29.

3.2.7 Cyclic Testing Test No. 20

The complex cyclic testing of UTP-3001 and UTP-19360B propellants was done with the 1/2 x 1/2 x 6-in. bar samples. These tests were run at 70% with cycling from 8 to 4% then 12 to 8% followed by 8 to 4% strain at a crosshead rate of 0.1 in./min. The strain levels were set so that the sample would not reach zero stress on the unload cycles. By doing that a correct evaluation of strain was obtained during the tests. Data for the UTP-19,360B propellant are shown as typical in Figure 59 with digitized results given in Table 30. This propellant broke without completing the nominal 30 cycles but UTP-3001 went all the way through the test. The nominal 10 cycles per segment was dependent upon when the time scale matched available personnel. It was 11 cycles for the first 2 segments for UTP-19360B as shown in Figure 59.

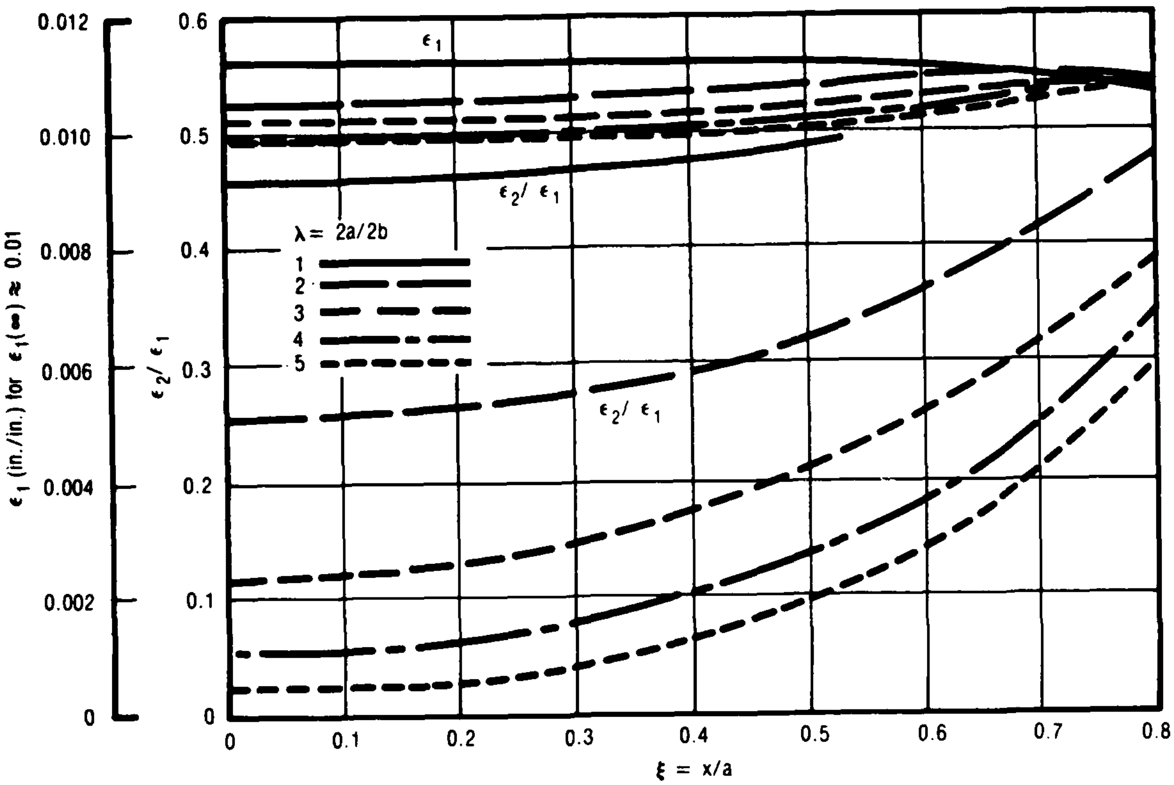


Figure 46. Strain Variations Along Midline of Strip Specimen (N = 0) for Poisson's Ratio of 1/2

28809

3.2.8 Biaxial Ramp-Relax-Ramp Test No. 21

The ramp-relax-ramp tests were run on UTP-3001 and UTP-19,360B propellants with the 1/4 x 1-1/4 x 6-in. biaxial specimens. The first test was ramped at 0.0005 in./min. to 6% strain and simultaneously cooled from 120 to 70°F. It was held at 6% strain nearly 23 hours then ramp to failure while cooling towards 40°F. The data for UTP-3001 are shown in Figure 60 with data points given in Table 31 as shown in Figure 60. The cooling cycle did not end at the peak strain consequently the relaxation of stress was not the normal type behavior. The continued cooling increased the propellant stress capability so that the normal relaxation behavior did not start until the propellant temperature stabilized.

This test was repeated starting at 110°F and taken to 6% strain with a peak stress of 70 psi compared to 30 psi for the above test. The longer ramp time

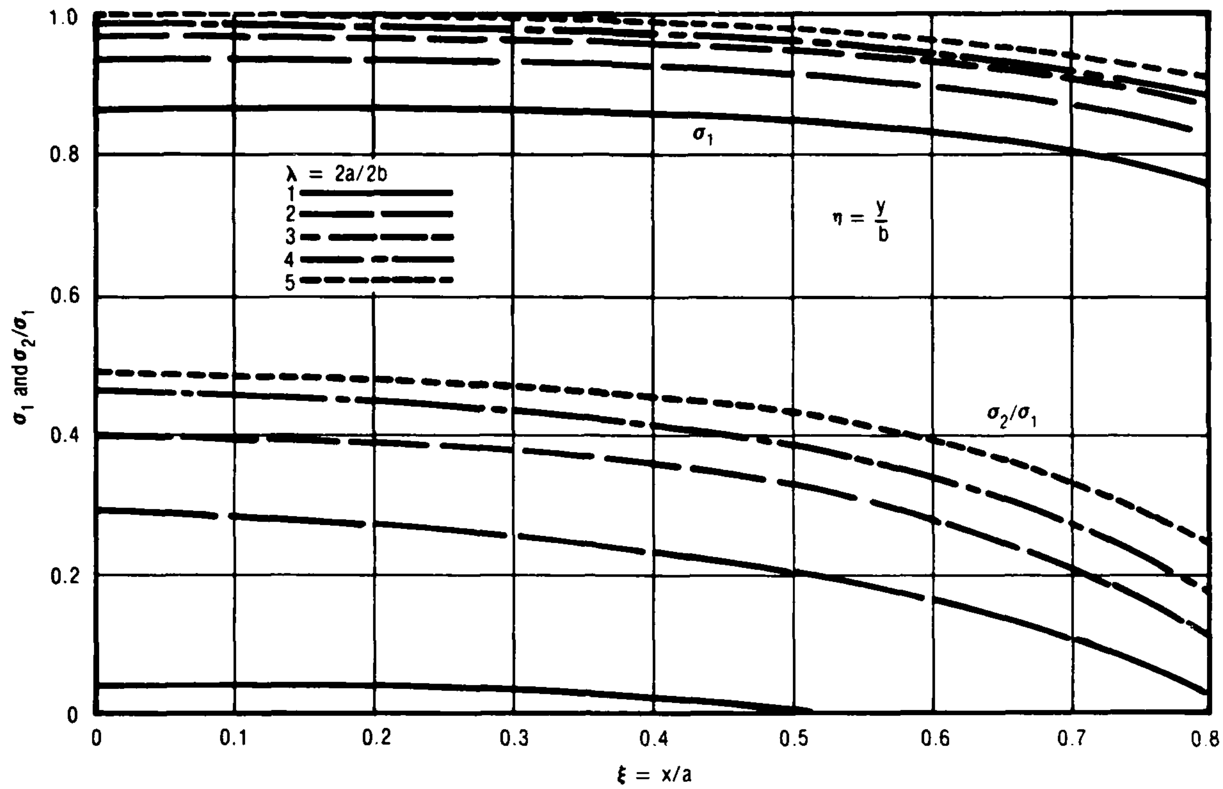


Figure 47. Stress Variations Along Midline of Strip Specimen (N = 0) for Poisson's Ratio of 1/2

28810

allowed the cooling to reach $40^{\circ}F$ at the peak stress. The samples were allowed to relax overnight and then unloaded to 3% while warming the samples to room temperature. Figure 60 was considered to be sufficient to represent the test.

3.2.9 Propellant Aging Effects During Phase III Testing

The biaxial testing in Phase III was scheduled to minimize the dry box storage time after sample machining. The purpose was to reduce the within carton or box variability encountered during the uniaxial testing in Phase II. The majority of the testing was accomplished within 1 week of machining the samples. Those that went over a week did not seem to be influenced excessively.

The data obtained for initial ramp loadings (i.e., undamaged behavior) on the tests run are given in Table 32 for UTP-3001 and Table 33 for UTP-19,360B. The biaxial constant rate data for UTP-3001 are plotted in Figure 61. These

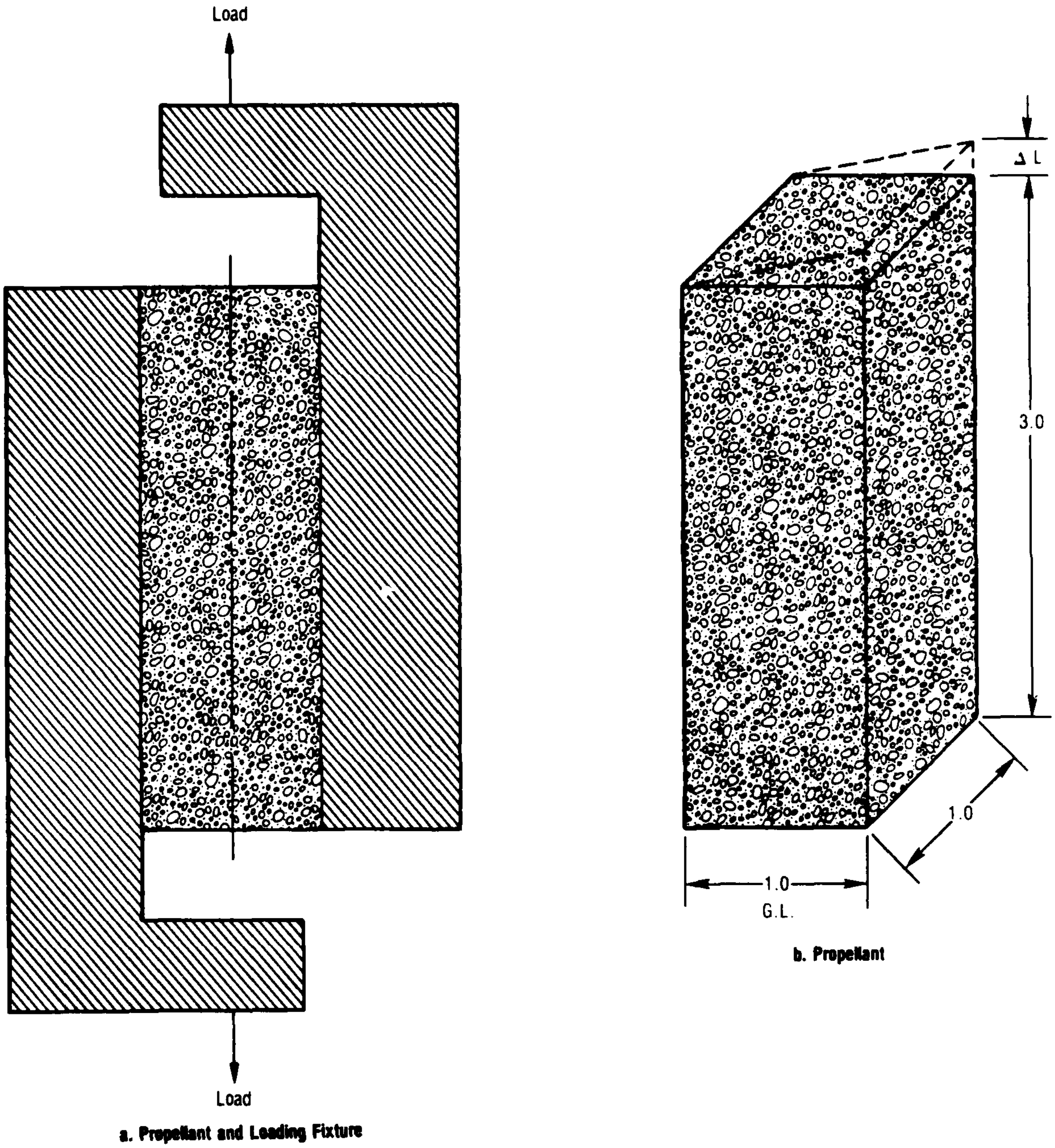


Figure 48. Shear Sample and Test Attachment

28811

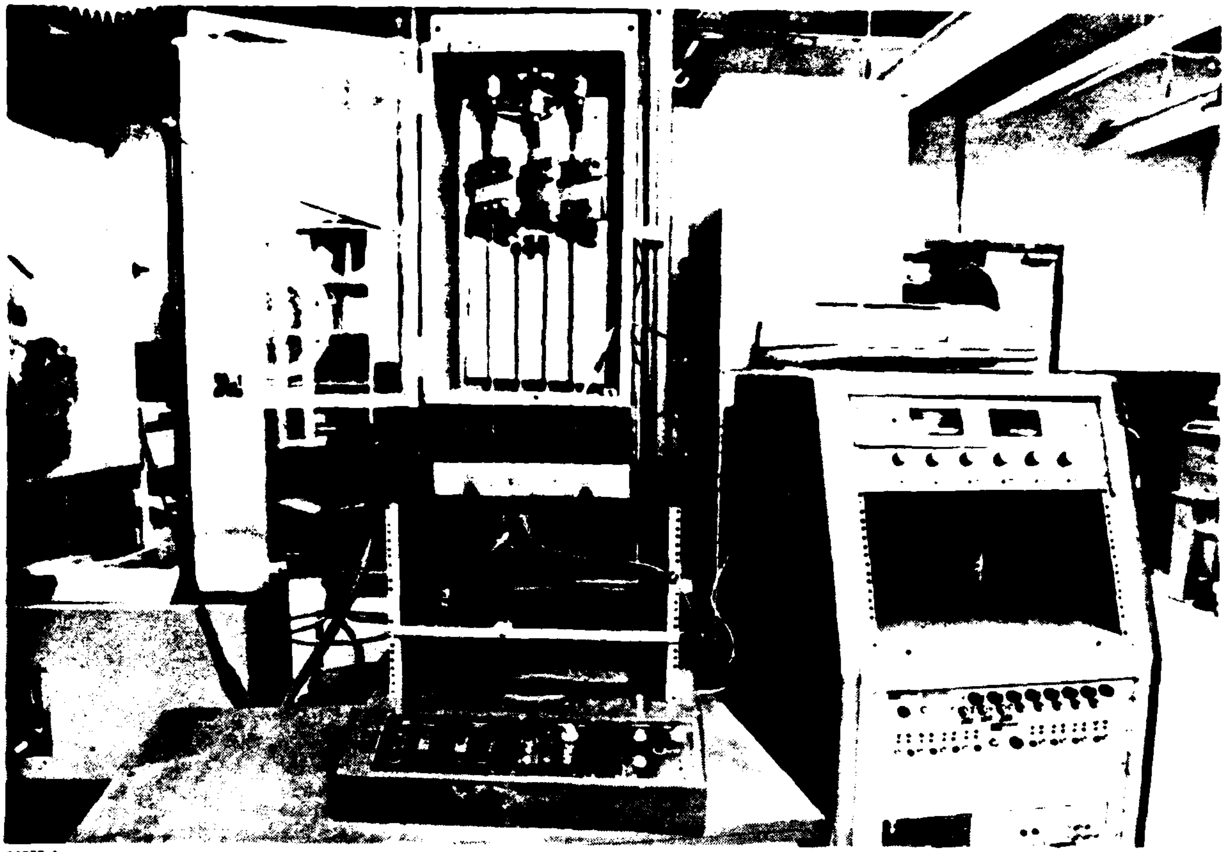


Figure 49. Biaxial Test Setup and Instrumentation

28385

results were used to obtain comparison data for other tests at different strain levels in Table 32. The stress at 8% strain versus temperature is shown in Figure 62 for UTP-3001. The tests at different temperatures were taken from different redwood boxes of propellant and there appears to be some between box and sample differences. The data shifted for rate effects to the 0.2 in./min. in the lower plot indicates that extrapolation of the temperature stress plot would be unreliable. This eliminated any reasonable direct comparison with the slower rate straining - cooling tests as noted in Table 32. The comparisons did show reasonable agreement with some samples from each of the redwood boxes used. The straining-cooling data are expected to be of the same general family.

(Text continued on page 168.)

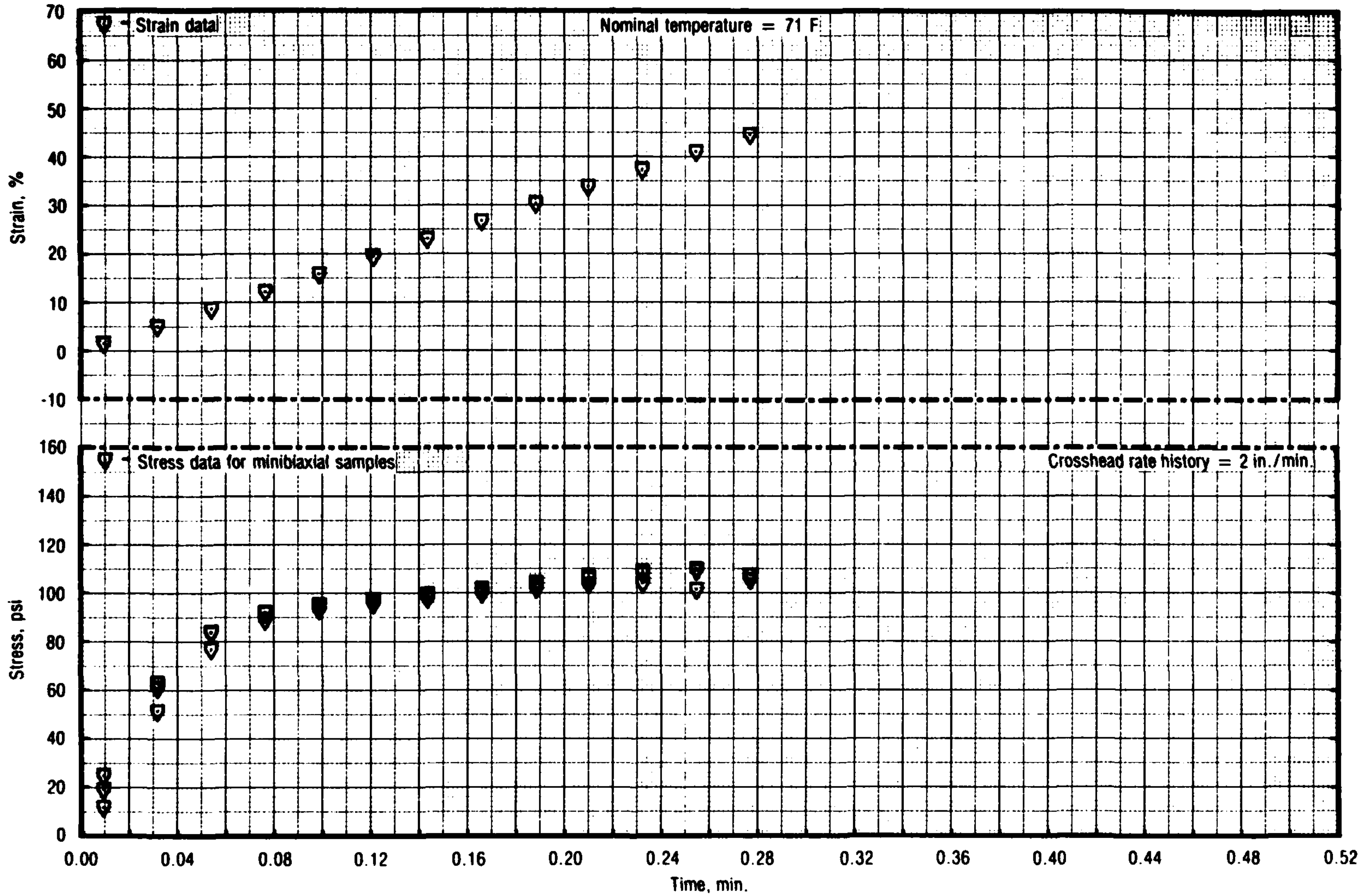


Figure 50. Test No. 14 - Stress for UTP-19,360B-400/1777

28812

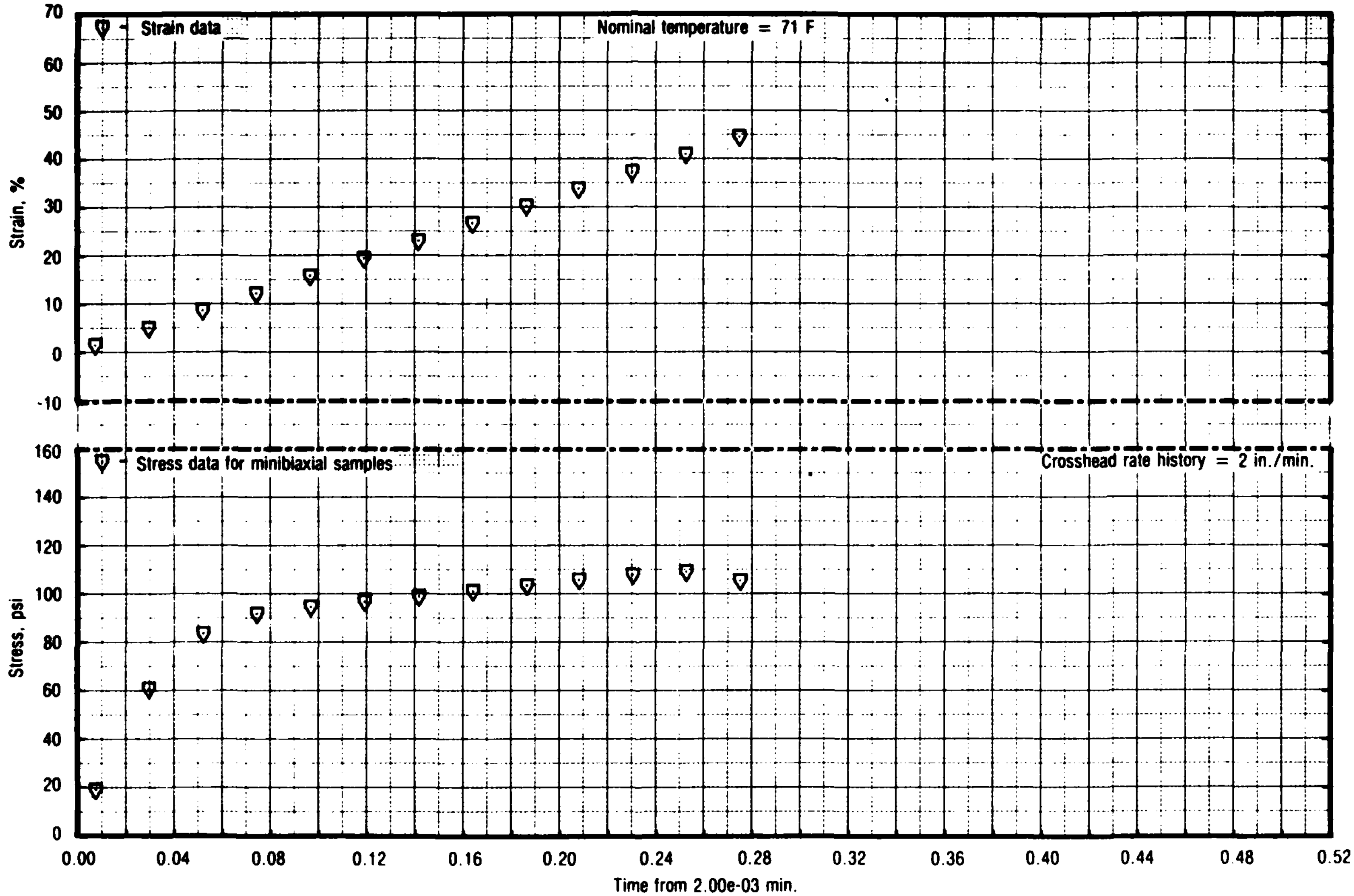


Figure 51. Test No. 14 - Stress for UTP-19,360B-400/1777

28813

TABLE 24. MINIBIAXIAL STRESS WHILE STRAINING AND COOLING

PROPELLANT: UTP 19360B 400/1777
REQUESTOR: Carlton,Francis
WOR: 2742-400-0000

DATE: 12/10/81
OPERATOR: JWD

DEFINITIONS:
Time = Time From Start of Test (min)
= Stress (psi)
= Strain (%)
T(air) = Test Air Temperature (F)
T(prop) = Test Propellant Temperature (F)

RELATIONSHIPS:
= Force/Area
= Sample Extension/Length

NOMINAL VALUES:
Test Temp = 71 F
Gage Length = 1.25 in
Nom. Strain = 50 %
XHD Rate = 2 in/min

CALIBRATION DATA:
Cal Wt = 10.0 lbs

	Sample 1	Sample 2	Sample 3
Load Cal (lbs/volts)	19.991	19.980	20.016
Offset (volts)	0.101	0.170	0.177
Pot Cal (in/volts) =	-0.393		
Temp (F) =	72.2		

AREAS (sq in):

Sample 1	Sample 2	Sample 3
1.537	1.494	1.512

STRESS DATA (psi):

SET	Time	T(prop)	T(air)	Strain	Sample 1	Sample 2	Sample 3	Avg	St Dev
1	0.00927	74.1	74.2	1.54	11.43	18.82	24.52	18.26	4.643
2	0.03159	74.0	74.3	5.08	51.21	60.76	62.81	58.26	4.378
3	0.05402	74.2	73.9	8.63	76.80	83.54	83.96	81.43	2.841
4	0.07639	73.9	73.4	12.20	88.77	91.74	92.06	90.86	1.282
5	0.09882	74.1	74.1	15.81	93.16	94.69	95.17	94.34	0.744
6	0.12120	74.0	73.9	19.42	95.50	96.76	97.25	96.50	0.639
7	0.14361	74.2	73.9	23.04	97.54	98.87	99.44	98.62	0.689
8	0.16604	74.3	74.2	26.68	99.65	101.07	101.68	100.80	0.737
9	0.18850	73.8	74.1	30.30	101.74	103.45	104.11	103.10	0.864
10	0.21011	74.1	74.1	33.79	103.47	105.80	106.48	105.25	1.119
11	0.23241	74.0	73.9	37.33	103.84	107.89	108.63	106.79	1.823
12	0.25480	74.0	74.1	40.98	101.26	109.12	109.78	106.72	3.352
13	0.27716	74.1	74.0	44.55		105.39	107.27	106.33	1.327

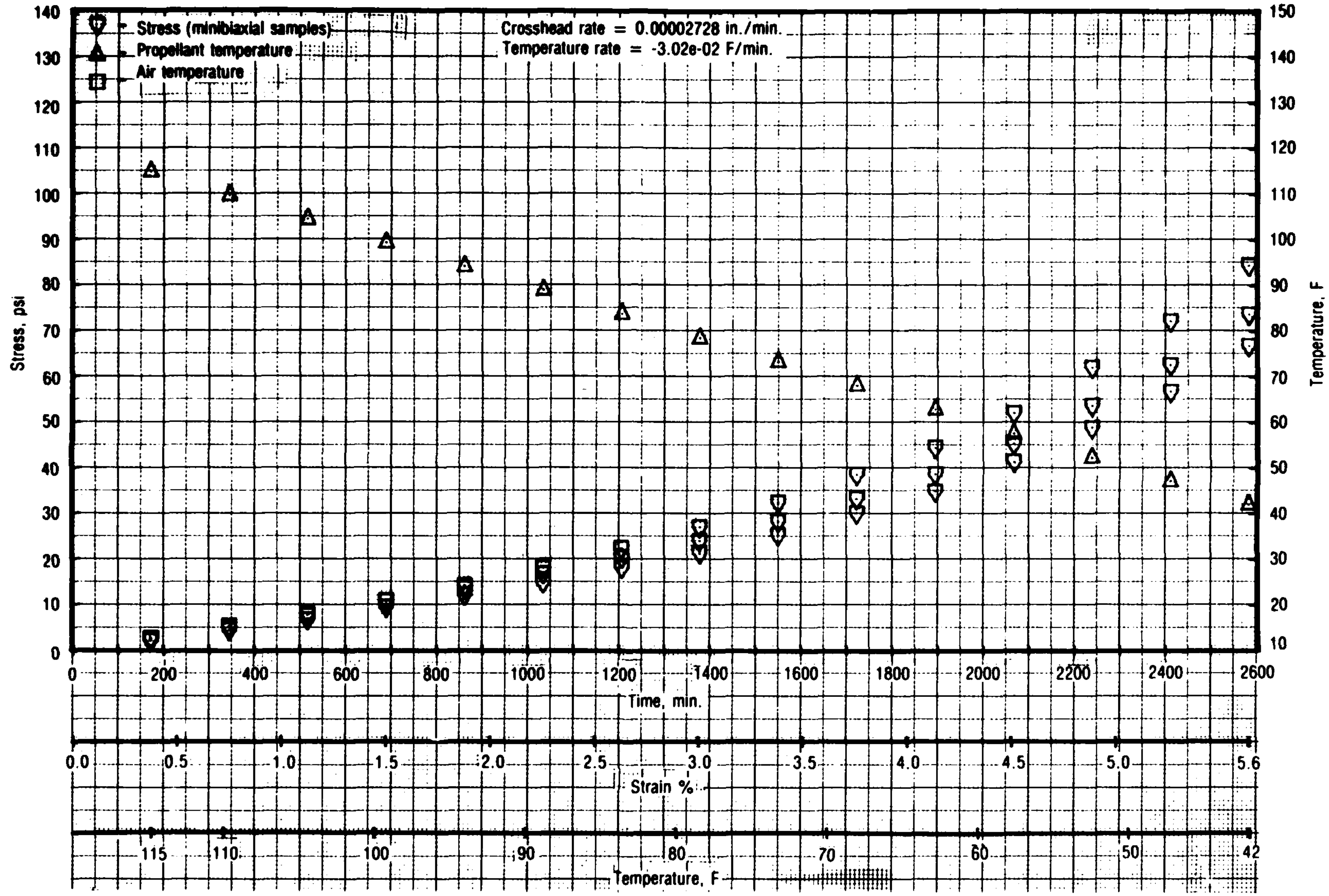


Figure 52. Stress While Straining and Cooling for UTP-3001-750/7768
28814

TABLE 25. MINIBIAXIAL STRESS WHILE STRAINING AND COOLING

PROPELLANT: UTP 3001 750/7768
REQUESTOR: Carlton Francis
WOR: 2242-400-0000

DATE: 12/22/81
OPERATOR: JWD

DEFINITIONS:

Time	=	Time From Start of Test (min)
σ	=	Stress (psi)
ε	=	Strain (%)
T(air)	=	Test Air Temperature (F)
T(prop)	=	Test Propellant Temperature (F)

RELATIONSHIPS:
σ = Force/Area
ε = Sample Extension/Length

NOMINAL VALUES:

Test Temp	=	120 to 40 F
Gage Length	=	1.25 in
Nom. Strain	=	10 %
XHD Rate	=	.00002728 in/min

CALIBRATION DATA:

			SAMPLE 1	SAMPLE 2	SAMPLE 3
Pretest:	Cal Wt = 10.0 lbs				
Load Cal	(lbs/in)		6.73	6.60	6.62
Offset	(in)		1.25	1.52	1.84
Temp	(F)	=	120.0		
Post Test:	Cal Wt = 10.0 lbs				
Load Cal	(lbs/in)		6.85	6.76	6.92
Offset	(in)		0.32	0.74	0.92
Temp	(F)	=	38.0		

	SAMPLE 1	SAMPLE 2	SAMPLE 3
AREAS (sq in):	0.885	0.834	0.879

STRESS DATA (psi):

SET	Time	T(prop)	T(air)	Strain	SAMPLE 1	SAMPLE 2	SAMPLE 3	Avg	St Dev
1	172.3000	114.8		0.38	2.05	2.33	2.63	2.34	0.286
2	344.5000	109.6		0.75	4.41	5.11	5.20	4.91	0.307
3	516.8000	104.4		1.13	6.77	7.73	7.94	7.48	0.441
4	689.1000	99.2		1.50	9.44	10.68	10.92	10.35	0.561
5	861.3000	94.0		1.88	12.05	13.48	14.07	13.20	0.732
6	1033.6000	88.8		2.26	14.81	16.77	18.01	16.53	1.140
7	1205.9000	83.6		2.63	18.04	20.23	22.27	20.18	1.497
8	1378.1000	78.4		3.01	21.27	24.01	27.02	24.10	2.034
9	1550.4000	73.2		3.38	25.21	28.21	32.42	28.61	2.561
10	1722.7000	68.0		3.76	30.07	33.23	38.54	33.95	3.026
11	1894.9000	62.8		4.14	34.87	38.66	44.46	39.33	3.415
12	2067.2000	57.6		4.51	41.37	45.40	52.13	46.30	3.842
13	2239.4000	52.4		4.89	48.89	53.77	62.10	54.92	4.723
14	2411.7000	47.2		5.26	56.82	62.65	72.29	63.92	5.525
15	2584.0000	42.0		5.64	66.85	73.74	84.49	75.03	6.289

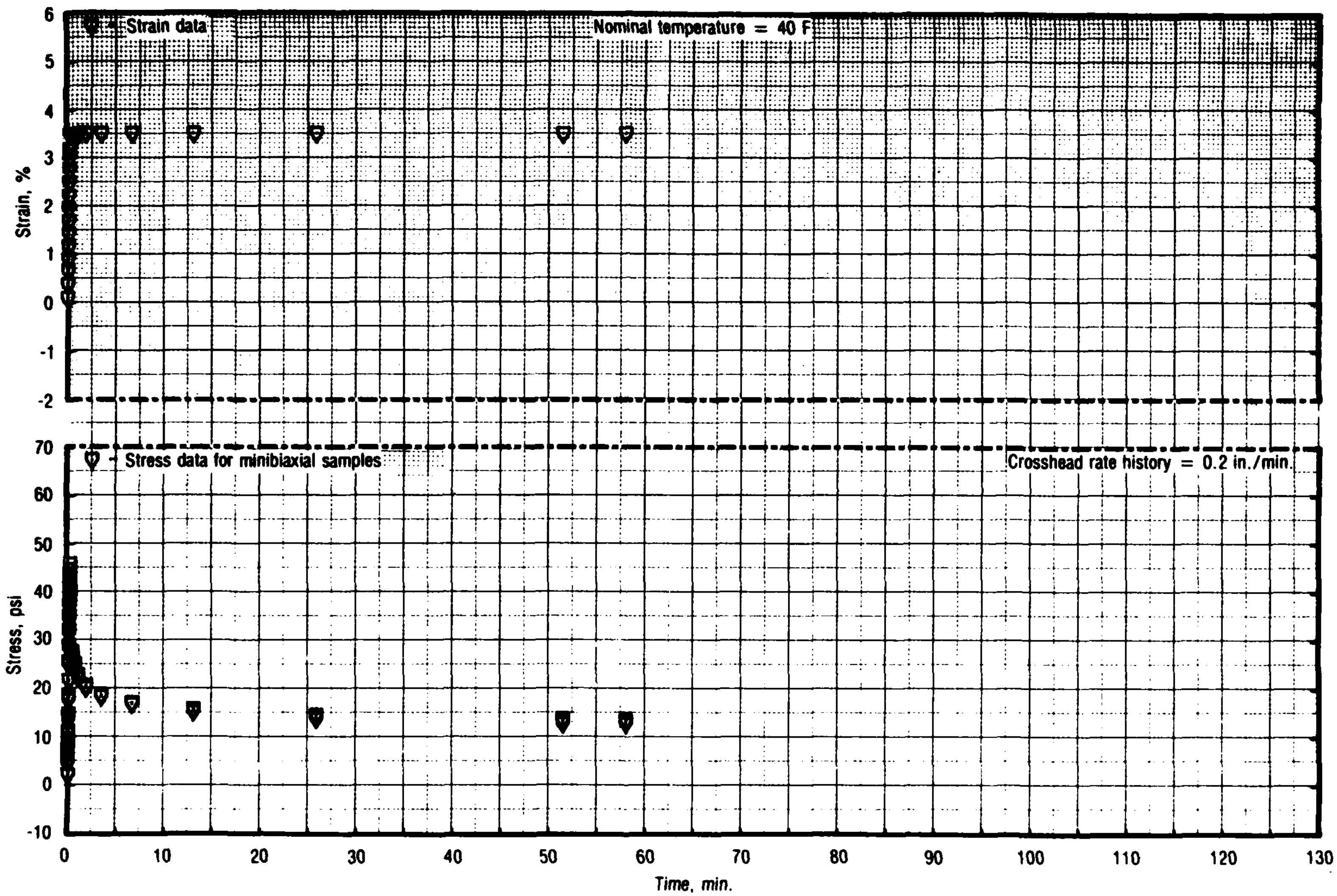


Figure 53. Test No. 16 - Stress While Step Straining for UTP-19,360B-400/177

28815

TABLE 26. MINIBIAXIAL STRESS WHILE STEP STRAINING

PROPELLANT: UTP 19360B 400/1777
REQUESTOR: Carlton
WOR: 2742-400-0000

DATE: 12-28-81
OPERATOR: BC

DEFINITIONS:
Time = Time From Start of Test (min)
σ = Stress (psi)
ϵ = Strain (%)
T(air) = Test Air Temperature (F)
T(prop) = Test Propellant Temperature (F)

RELATIONSHIPS:
σ = Force/Area
ϵ = Sample Extension/Length

NOMINAL VALUES:
Test Temp = 40 F
Gage Length = 1.25 in
Nom. Strain = 3 %
XHD Rate = .2 in/min

CALIBRATION DATA:

		Sample 1	Sample 2	Sample 3
Cal Wt = 10.0 lbs				
Load Cal	(lbs/volts)	29.816	29.773	30.009
Offset	(volts)	0.058	0.251	0.071
Pot Cal	(in/volts) =	-0.385		
Temp	(F) =	42.1		

AREAS (sq in): 1.478 1.478 1.478

STRESS DATA (psi):

SET	Time	T(prop)	T(air)	Strain	Sample 1	Sample 2	Sample 3	Avg	St Dev
1	0.00823	42.1	43.0	0.11	2.04	2.17	2.09	2.10	0.047
2	0.02525	43.1	42.0	0.39	4.58	6.47	4.96	5.34	0.709
3	0.04242	42.0	41.9	0.67	7.79	10.58	9.39	9.25	0.989
4	0.05957	42.8	41.7	0.91	11.22	14.41	13.53	13.05	1.163
5	0.07672	42.9	41.4	1.17	14.75	18.16	17.61	16.84	1.293
6	0.09397	42.6	41.5	1.43	18.15	21.68	21.64	20.49	1.431
7	0.11116	42.9	41.2	1.69	21.68	25.23	25.53	24.15	1.514
8	0.12759	42.5	41.4	1.95	24.98	28.51	28.94	27.48	1.538
9	0.14468	42.3	41.3	2.22	28.23	31.73	32.21	30.72	1.535
10	0.16188	42.3	41.1	2.50	31.38	34.84	35.11	33.78	1.470
11	0.17913	42.4	41.3	2.76	34.39	37.82	37.10	36.44	1.272
12	0.19632			3.02	37.40	40.79	39.08	39.09	1.198
13	0.20809			3.20	39.45	42.82	40.44	40.90	1.222
14	0.22900	42.7	41.1	3.50	42.65	45.88	43.46	44.00	1.188
15	0.23369			3.50	41.61	44.64	42.14	42.80	1.144
16	0.50936	42.4	43.3	3.50	26.29	27.51	26.64	26.81	0.444
17	0.70987	42.9	40.8	3.51	24.23	25.21	24.63	24.69	0.351
18	1.11024	42.7	40.9	3.51	22.09	22.85	22.48	22.47	0.269
19	1.91093	42.3	41.0	3.52	20.06	20.58	20.45	20.36	0.189
20	3.51132	42.4	41.1	3.53	18.31	18.61	18.67	18.53	0.135
21	6.71208	42.6	42.4	3.52	16.81	16.76	17.11	16.89	0.133
22	13.11242	42.9	40.8	3.52	15.53	15.22	15.77	15.51	0.196
23	25.91287	43.0	41.5	3.52	14.33	13.80	14.52	14.22	0.261
24	51.51364	42.3	40.8	3.50	13.44	12.70	13.56	13.26	0.295
25	58.05404	42.4	40.5	3.51	13.32	12.75	13.44	13.17	0.261

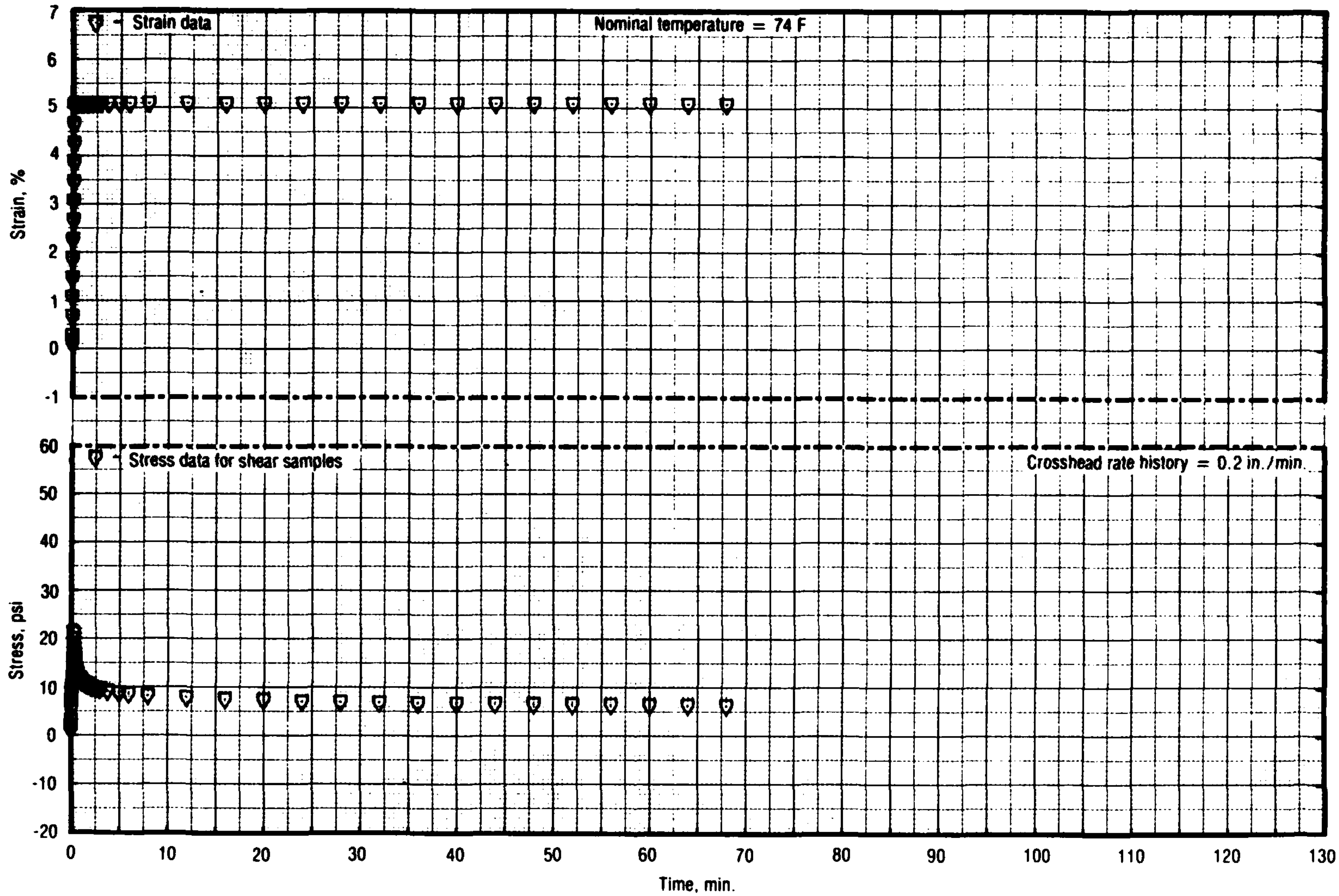


Figure 54. Test No. 17 - Stress While Step Straining for UTP-3001-750/7768

28816

TABLE 27. SHEAR STRESS WHILE STEP STRAINING
(SHEET 1 OF 2)

PROPELLANT: UTP 3001 750/7768
REQUESTOR: Carlton Francis
WOR: 2742-400-0000

DATE: 12/81
OPERATOR: JWD/BS

DEFINITIONS:
Time = Time From Start of Test (min)
= Stress (psi)
= Strain (%)
T(air) = Test Air Temperature (F)
T(prop) = Test Propellant Temperature (F)

RELATIONSHIPS:
= Force/Area
= Sample Extension/Length

NOMINAL VALUES:
Test Temp = 74 F
Gage Length = 1.01 in
Nom. Strain = 6 %
XHD Rate = .2 in/min

CALIBRATION DATA:	SAMPLE 1
Cal Wt = 10.0 lbs	
Load Cal (lbs/in)	20.000
Offset (in)	0.000
Temp (F)	74.0

AREAS (sq in): 3.004

STRESS DATA (psi):

SET	Time	T(prop)	T(air)	Strain	SAMPLE 1	Avg	St Dev
1	0.00600			0.12	1.20	1.20	0.000
2	0.01400			0.28	2.00	2.00	0.000
3	0.03400			0.68	3.13	3.13	0.000
4	0.05400			1.07	5.59	5.59	0.000
5	0.07400			1.47	7.32	7.32	0.000
6	0.09400			1.87	8.66	8.66	0.000
7	0.11400			2.26	9.99	9.99	0.000
8	0.13400			2.66	11.45	11.45	0.000
9	0.15400			3.06	12.72	12.72	0.000
10	0.17400			3.46	13.98	13.98	0.000
11	0.19400			3.85	15.45	15.45	0.000
12	0.21400			4.25	16.98	16.98	0.000
13	0.23400			4.65	18.44	18.44	0.000
14	0.25400			5.04	19.97	19.97	0.000
15	0.25600			5.08	21.30	21.30	0.000
16	0.27600			5.08	19.97	19.97	0.000
17	0.29600			5.08	18.64	18.64	0.000
18	0.31600			5.08	17.38	17.38	0.000
19	0.37600			5.08	16.05	16.05	0.000
20	0.43600			5.08	14.71	14.71	0.000
21	0.47600			5.08	13.98	13.98	0.000
22	0.57600			5.08	13.32	13.32	0.000
23	0.65600			5.08	12.72	12.72	0.000
24	0.83600			5.08	11.98	11.98	0.000
25	1.03600			5.08	11.45	11.45	0.000
26	1.23600			5.08	11.05	11.05	0.000
27	1.43600			5.08	10.72	10.72	0.000
28	1.63600			5.08	10.52	10.52	0.000
29	1.83600			5.08	10.32	10.32	0.000

TABLE 27. SHEAR STRESS WHILE STEP STRAINING
(SHEET 2 OF 2)

30	2.23600	5.08	9.92	9.92	0.000
31	2.63600	5.08	9.72	9.72	0.000
32	3.03600	5.08	9.45	9.45	0.000
33	3.83600	5.08	9.19	9.19	0.000
34	5.03600	5.08	8.79	8.79	0.000
35	6.03600	5.08	8.59	8.59	0.000
36	8.03600	5.08	8.26	8.26	0.000
37	12.03600	5.08	7.86	7.86	0.000
38	16.03600	5.08	7.52	7.52	0.000
39	20.03600	5.08	7.39	7.39	0.000
40	24.03600	5.08	7.12	7.12	0.000
41	28.03600	5.08	6.99	6.99	0.000
42	32.03600	5.08	6.86	6.86	0.000
43	36.03600	5.08	6.79	6.79	0.000
44	40.03600	5.08	6.72	6.72	0.000
45	44.03600	5.08	6.66	6.66	0.000
46	48.03600	5.08	6.59	6.59	0.000
47	52.03600	5.08	6.52	6.52	0.000
48	56.03600	5.08	6.46	6.46	0.000
49	60.03600	5.08	6.42	6.42	0.000
50	64.03600	5.08	6.39	6.39	0.000
51	68.03600	5.08	6.32	6.32	0.000

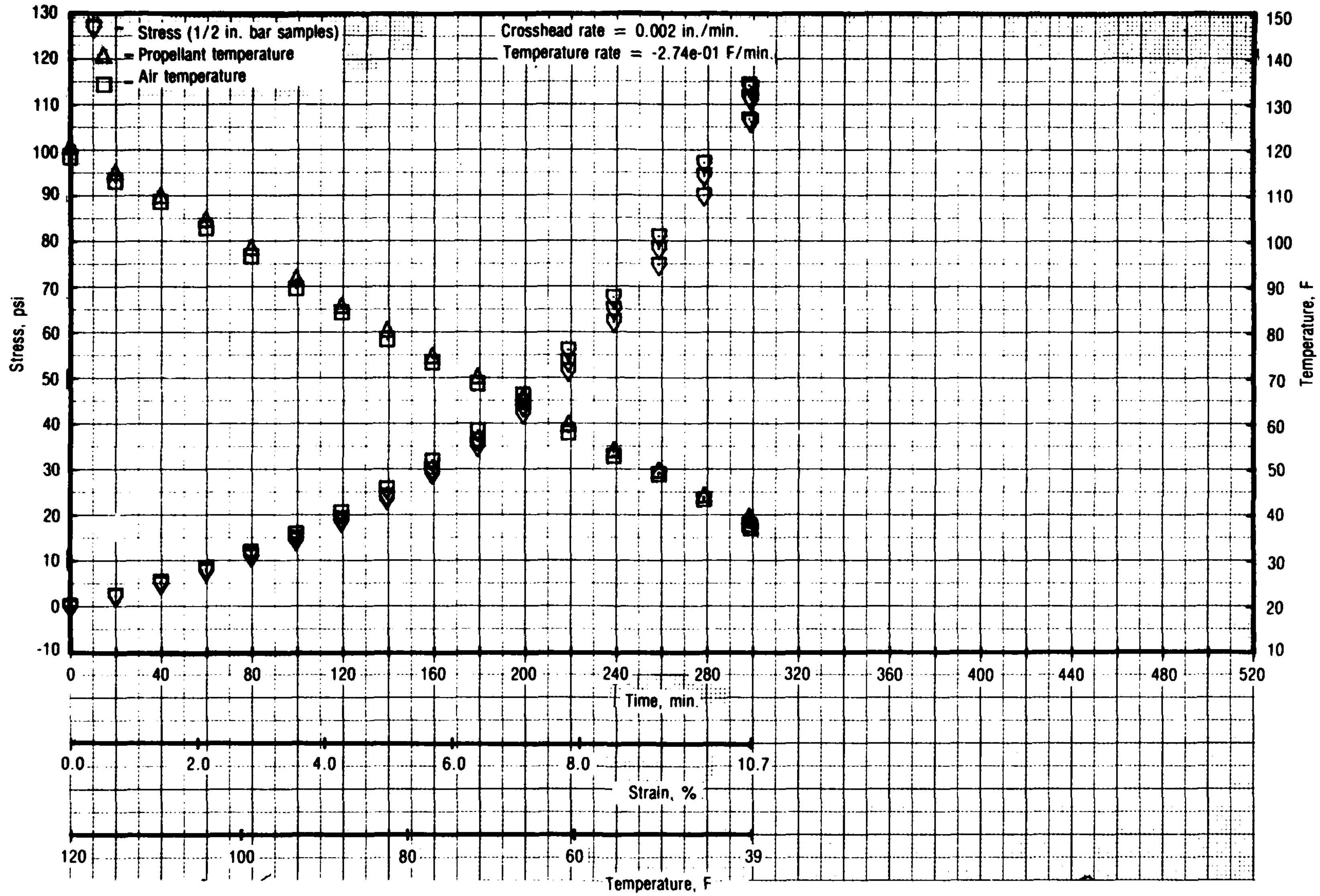


Figure 55. Test No. 18 - Stress While Straining and Cooling for UTP-3001-750/7768

28817

TABLE 28. 1/2-IN. BAR STRESS WHILE STRAINING AND COOLING

PROPELLANT: UTP 3001 750/7768
REQUESTOR: Carlton Francis
WOR: 2742-400-0000

DATE: 12/2/81
OPERATOR: JWD

DEFINITIONS:
Time = Time From Start of Test (min)
= Stress (psi)
= Strain (%)
T(air) = Test Air Temperature (F)
T(prop) = Test Propellant Temperature (F)

RELATIONSHIPS:
= Force/Area
= Sample Extension/Length

NOMINAL VALUES:
Test Temp = 120 to 40 F
Gage Length = 5.97 in
Nom. Strain = 10 %
XHD Rate = .002 in/min

CALIBRATION DATA:

		SAMPLE 1	SAMPLE 2	SAMPLE 3
Pretest:	Cal Wt = 10.0 lbs			
Load Cal	(lbs/volts)	-4.03	-4.43	-4.13
Offset	(volts)	0.01	-0.00	-0.02
Pot Cal	(in/volts) =	-0.85		
Temp	(F) =	120.6		
Post Test:	Cal Wt = 10.0 lbs			
Load Cal	(lbs/volts)	-4.07	-4.51	-4.17
Offset	(volts)	0.56	0.43	0.16
Pot Cal	(in/volts) =	-0.86		
Temp	(F) =	39.1		
AREAS (sq in):		0.228	0.228	0.230

STRESS DATA (psi):

Time	T(prop)	T(air)	Strain	SAMPLE 1	SAMPLE 2	SAMPLE 3	Avg	St Dev
0.00E 00	120.5	118.5	0.00	0.02	0.15	-0.02	0.05	0.062
1.99E 01	114.7	113.1	0.67	2.44	2.43	2.22	2.37	0.089
3.98E 01	109.5	108.7	1.35	5.41	5.16	4.96	5.18	0.160
5.97E 01	104.4	103.0	1.95	8.34	7.85	7.73	7.97	0.229
7.96E 01	98.2	96.8	2.59	11.98	11.30	10.97	11.42	0.361
9.95E 01	91.5	89.7	3.32	15.96	15.05	14.52	15.18	0.518
1.19E 02	85.4	84.4	3.90	20.63	19.25	18.66	19.52	0.714
1.39E 02	80.1	78.5	4.53	25.83	24.19	23.55	24.52	0.832
1.59E 02	74.4	73.4	5.33	31.97	30.03	29.10	30.37	1.033
1.79E 02	69.9	68.9	6.03	38.54	36.41	35.15	36.70	1.211
1.99E 02	65.3	64.8	6.75	46.29	43.95	42.34	44.20	1.405
2.19E 02	59.5	58.1	7.56	56.17	53.64	51.59	53.80	1.622
2.39E 02	53.7	53.0	8.29	67.72	65.08	62.34	65.05	1.905
2.59E 02	49.4	49.0	9.03	81.11	78.37	74.87	78.12	2.212
2.79E 02	43.9	43.5	9.90	97.19	94.38	90.07	93.88	2.537
2.98E 02	39.3	37.9	10.68	114.28	111.75	106.82	110.95	2.681
2.99E 02	38.6	37.1	10.69	113.76	111.18	106.32	110.42	2.672

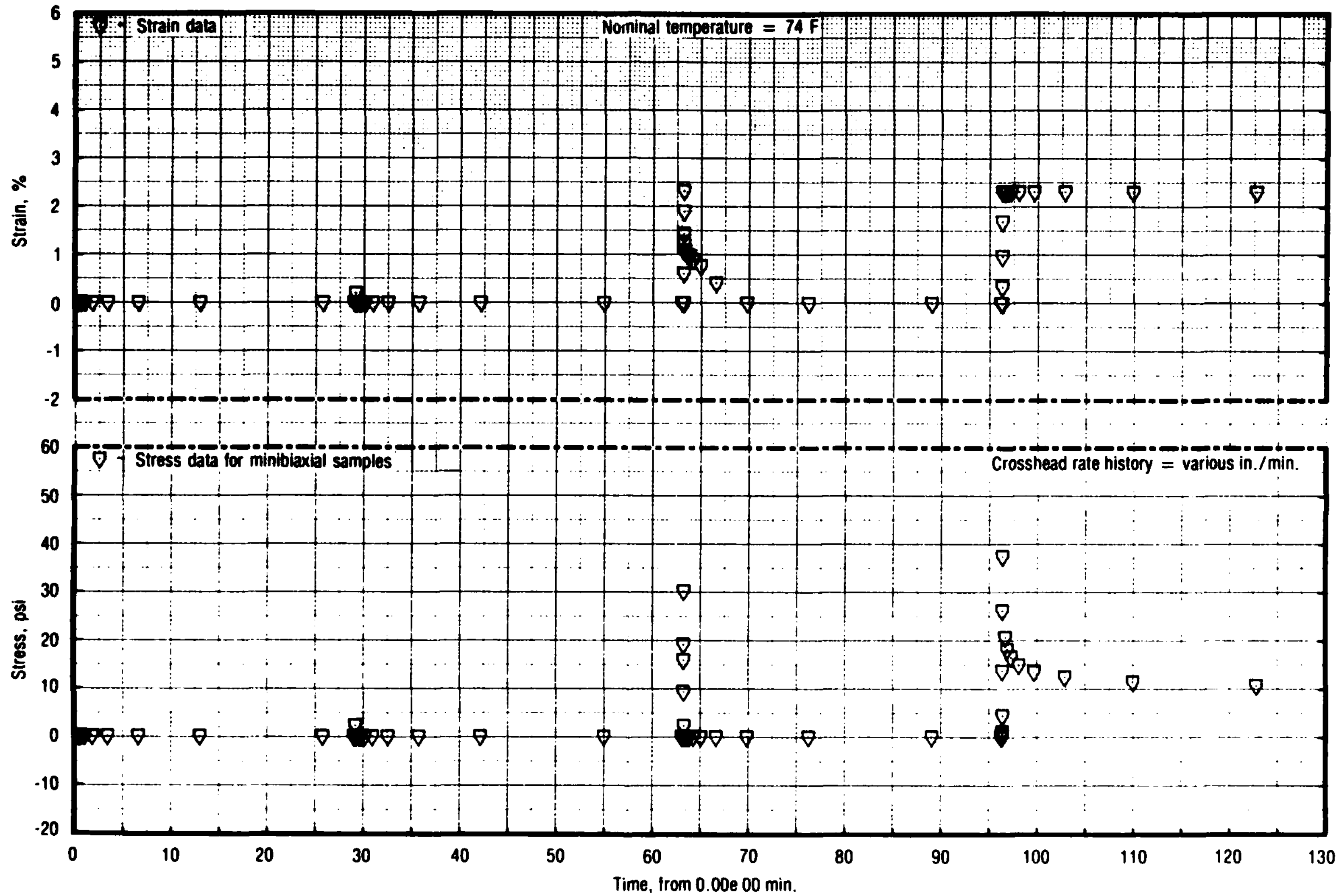


Figure 56. Test No. 19, Part 1 - Stress for UTP-3001-750/7768

28818

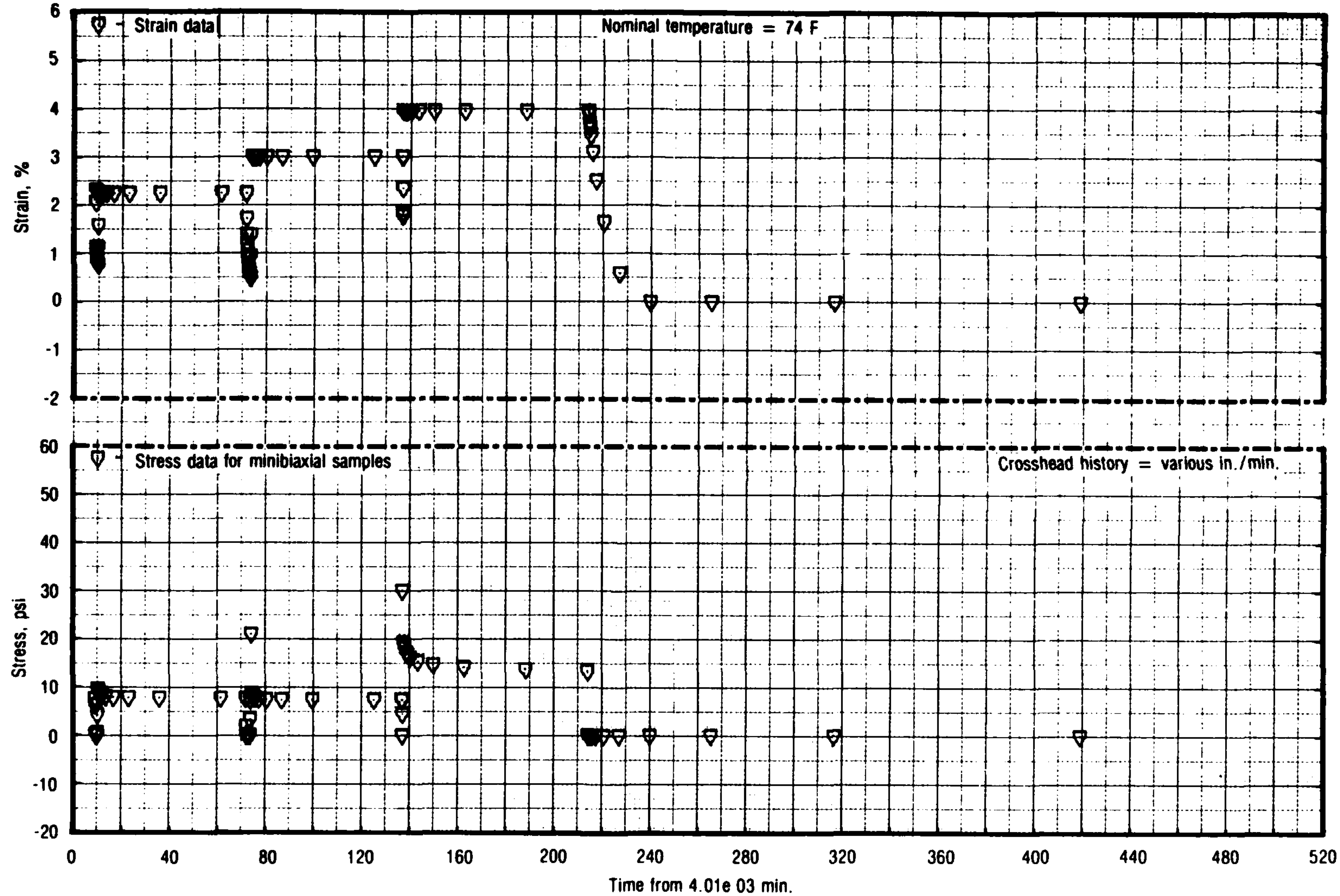


Figure 57. Test No. 19, Part 2 - Stress for UTP-3001-750/7768

28819

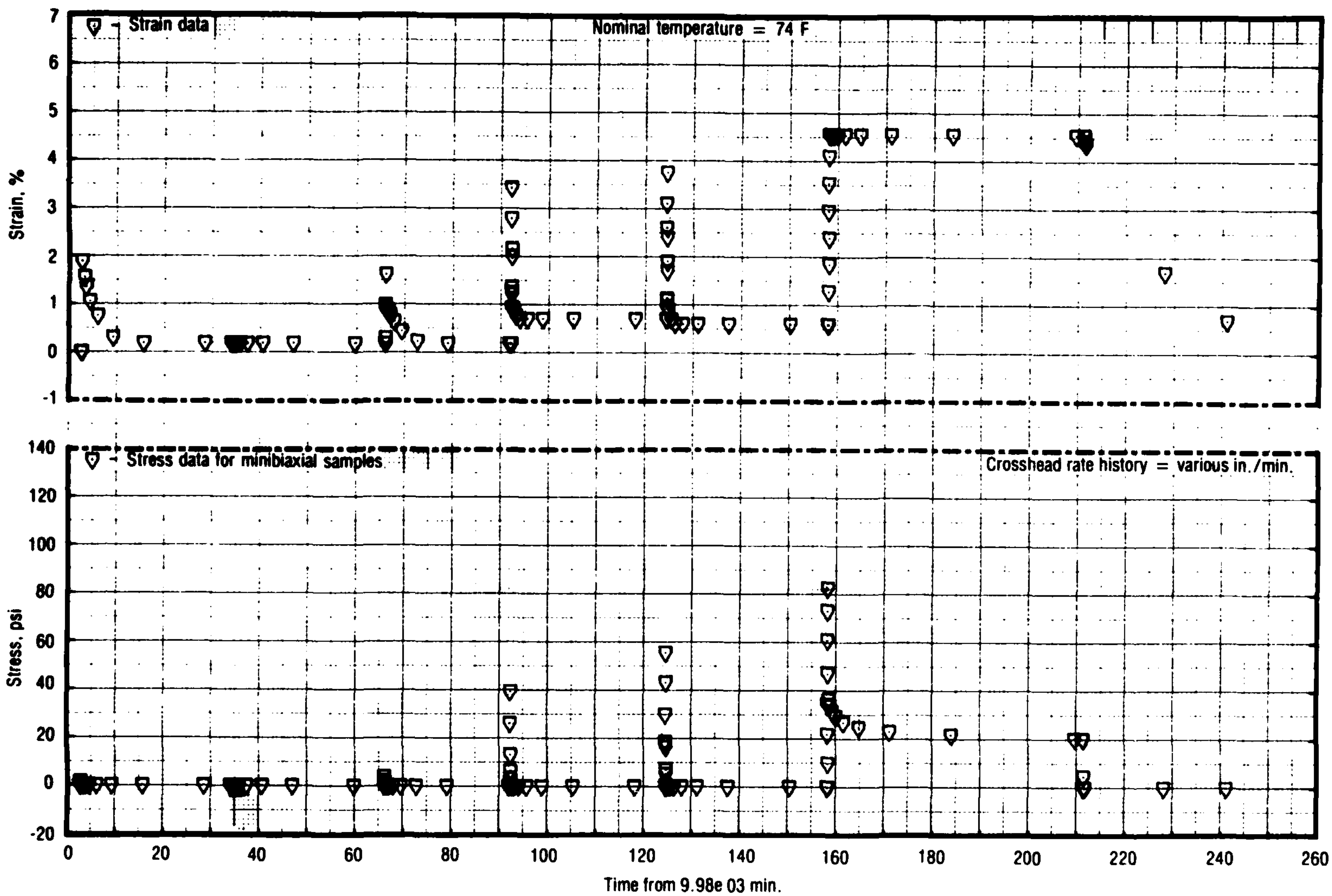


Figure 58. Test No. 19, Part 3 - Stress for UTP-3001-750/7768

28820

TABLE 29. TEST NO. 19 - MINIBIAXIAL STRESS, SAMPLE
(SHEET 1 OF 6)

PROPELLANT: UTP 3001 750/7768
REQUESTOR: Carlton Francis
WOR: 2742-400-0000

DATE: 1/18/82 S1
OPERATOR: JWD

DEFINITIONS:
- Time = Time From Start of Test (min)
- σ = Stress (psi)
- ϵ = Strain (%)
- T(air) = Test Air Temperature (F)
- T(prop) = Test Propellant Temperature (F)

RELATIONSHIPS:
- σ = Force/Area
- ϵ = Sample Extension/Length

NOMINAL VALUES:
- Test Temp = 74 F
- Gage Length = 1.25 in
- Nom. Strain = Various %
- XHD Rate = Various in/min

CALIBRATION DATA:		SAMPLE 1
Cal Wt = 10.0 lbs		
Load Cal	(lbs/volts)	29.768
Offset	(volts)	0.083
Pot Cal	(in/volts) =	-0.396
Temp	(F) =	77.1

AREAS (sq in): 1.477

STRESS DATA (psi):

SET	Time	T(prop)	T(air)	Strain	SAMPLE 1	Avg	St Dev
1	0.00882			0.00	0.00	0.00	0.000
2	0.01450			0.00	0.00	0.00	0.000
3	0.02154			0.00	0.00	0.00	0.000
4	0.02793			0.00	0.00	0.00	0.000
5	0.03523			0.00	0.00	0.00	0.000
6	0.04142			0.00	0.00	0.00	0.000
7	0.04766			0.00	0.00	0.00	0.000
8	0.35506	80.4	79.4	0.00	0.00	0.00	0.000
9	0.55560	80.0	78.8	0.00	0.00	0.00	0.000
10	0.95656	80.0	79.4	0.00	0.00	0.00	0.000
11	1.75691	80.2	79.1	0.00	0.00	0.00	0.000
12	3.35766	80.0	79.3	0.00	0.00	0.00	0.000
13	6.55836	79.0	77.1	0.00	0.00	0.00	0.000
14	12.95926	77.4	75.9	0.00	0.00	0.00	0.000
15	25.75954	77.2	76.5	0.00	0.00	0.00	0.000
16	29.01546	78.0	76.9	0.00	0.00	0.00	0.000
17	29.11100			0.00	0.00	0.00	0.000
18	29.11966			0.00	0.00	0.00	0.000
19	29.12405			0.00	0.00	0.00	0.000
20	29.12845			0.00	0.00	0.00	0.000
21	29.13286			0.00	0.00	0.00	0.000
22	29.13729			0.00	0.00	0.00	0.000
23	29.14171			0.00	0.00	0.00	0.000
24	29.14613			0.00	0.00	0.00	0.000
25	29.15056			0.00	0.00	0.00	0.000
26	29.15497			0.00	0.00	0.00	0.000
27	29.15937			0.00	0.00	0.00	0.000
28	29.16379			0.20	2.31	2.31	0.000
29	29.17066			0.00	0.00	0.00	0.000
30	29.17507			0.00	0.00	0.00	0.000
31	29.17948			0.00	0.00	0.00	0.000

TABLE 29. TEST NO. 19 - MINIBIAXIAL STRESS, SAMPLE
(SHEET 2 OF 6)

32	29.18388			0.00	0.00	0.00	0.000
33	29.18829			0.00	0.00	0.00	0.000
34	29.19269			0.00	0.00	0.00	0.000
35	29.19711			0.00	0.00	0.00	0.000
36	29.20152			0.00	0.00	0.00	0.000
37	29.20591			0.00	0.00	0.00	0.000
38	29.21029			0.00	0.00	0.00	0.000
39	29.21469			0.00	0.00	0.00	0.000
40	29.51695	78.1	77.1	0.00	0.00	0.00	0.000
41	29.71754	78.4	77.2	0.00	0.00	0.00	0.000
42	30.11837	78.1	77.1	0.00	0.00	0.00	0.000
43	30.91859	78.1	77.3	0.00	0.00	0.00	0.000
44	32.51906	78.9	77.7	0.00	0.00	0.00	0.000
45	35.71934	78.5	77.3	0.00	0.00	0.00	0.000
46	42.11967	78.7	77.2	0.00	0.00	0.00	0.000
47	54.92033	77.0	76.0	0.00	0.00	0.00	0.000
48	63.03302	77.6	76.8	0.00	0.00	0.00	0.000
49	63.17093			0.00	0.00	0.00	0.000
50	63.17558			0.00	0.00	0.00	0.000
51	63.18441			0.00	0.00	0.00	0.000
52	63.19243			0.00	0.00	0.00	0.000
53	63.20051			0.00	0.00	0.00	0.000
54	63.20948			0.00	0.00	0.00	0.000
55	63.21500			0.00	0.00	0.00	0.000
56	63.22560			0.62	9.36	9.36	0.000
57	63.23449			1.44	19.19	19.19	0.000
58	63.24400			2.33	30.20	30.20	0.000
59	63.24977			1.90	15.91	15.91	0.000
60	63.25865			1.24	2.28	2.28	0.000
61	63.26671			1.09	0.12	0.12	0.000
62	63.27478			1.09	0.00	0.00	0.000
63	63.28373			1.08	0.00	0.00	0.000
64	63.29179			1.08	0.00	0.00	0.000
65	63.29986			1.07	0.00	0.00	0.000
66	63.30300			1.07	0.00	0.00	0.000
67	63.31688			1.07	0.00	0.00	0.000
68	63.61307	77.5	77.0	1.00	0.00	0.00	0.000
69	63.81334	77.9	77.0	0.98	0.00	0.00	0.000
70	64.21378	77.8	76.9	0.90	0.00	0.00	0.000
71	65.01426	77.6	77.3	0.77	0.00	0.00	0.000
72	66.61475	78.2	77.0	0.42	0.00	0.00	0.000
73	69.81525	77.8	76.8	0.00	0.00	0.00	0.000
74	76.21550	77.7	76.6	0.00	0.00	0.00	0.000
75	89.01615	77.8	76.3	0.00	0.00	0.00	0.000
76	96.19476	76.9	76.5	0.00	0.00	0.00	0.000
77	96.27000			0.00	0.00	0.00	0.000
78	96.30100			0.00	0.00	0.00	0.000
79	96.30888			0.00	0.37	0.37	0.000
80	96.31697			0.00	0.48	0.48	0.000
81	96.32504			0.00	0.61	0.61	0.000
82	96.33900			0.00	1.19	1.19	0.000
83	96.34202			0.35	4.50	4.50	0.000
84	96.35010			0.98	13.75	13.75	0.000
85	96.35904			1.70	26.22	26.22	0.000
86	96.36713			2.32	37.49	37.49	0.000
87	96.66950	77.1	76.5	2.32	20.70	20.70	0.000
88	96.87046	77.4	76.4	2.32	18.20	18.20	0.000

TABLE 29. TEST NO. 19 - MINIBIAXIAL STRESS, SAMPLE (SHEET 3 OF 6)

89	97.27119	77.2	76.4	2.32	16.58	16.58	0.000
90	98.07191	77.7	76.8	2.32	14.98	14.98	0.000
91	99.67222	78.2	77.1	2.32	13.57	13.57	0.000
92	102.87297	78.0	76.8	2.32	12.49	12.49	0.000
93	109.95481	77.9	76.9	2.32	11.51	11.51	0.000
94	122.75506	77.9	76.9	2.32	10.75	10.75	0.000
95	148.35598	77.0	76.4	2.32	10.03	10.03	0.000
96	199.55619	76.2	75.9	2.32	9.41	9.41	0.000
97	301.95647	76.7	76.4	2.32	8.79	8.79	0.000
98	506.75673	76.0	75.7	2.32	8.23	8.23	0.000
99	916.35741	75.2	74.1	2.32	8.10	8.10	0.000
100	1735.55786	76.9	76.5	2.32	7.90	7.90	0.000
101	3373.95836	73.0	73.4	2.32	7.60	7.60	0.000
102	4018.89852	72.8	73.0	2.32	7.50	7.50	0.000
103	4018.96500			2.32	7.50	7.50	0.000
104	4018.99338	72.9	72.7	2.06	6.17	6.17	0.000
105	4019.10492	72.8	72.9	1.14	0.13	0.13	0.000
106	4019.16003	73.1	72.6	1.04	0.00	0.00	0.000
107	4019.21589	72.7	72.7	0.96	0.00	0.00	0.000
108	4019.27155	72.9	72.8	0.90	0.00	0.00	0.000
109	4019.32726	72.7	72.9	0.86	0.00	0.00	0.000
110	4019.38217	72.9	72.8	0.81	0.00	0.00	0.000
111	4019.43774	72.9	72.6	0.80	0.00	0.00	0.000
112	4019.51315			0.78	0.00	0.00	0.000
113	4019.56893	73.2	72.6	0.78	0.00	0.00	0.000
114	4019.62442	73.3	72.2	0.77	0.00	0.00	0.000
115	4019.69200	72.5	73.0	0.77	0.00	0.00	0.000
116	4019.73594	72.5	72.8	0.77	0.00	0.00	0.000
117	4019.80500	73.1	72.6	0.77	0.00	0.00	0.000
118	4019.84646	73.5	72.9	1.12	0.52	0.52	0.000
119	4019.90266	72.8	72.7	1.58	4.18	4.18	0.000
120	4019.98000			2.25	9.50	9.50	0.000
121	4020.30073	72.7	73.0	2.25	9.03	9.03	0.000
122	4020.50095	73.2	72.5	2.25	8.74	8.74	0.000
123	4020.90133	73.0	72.7	2.25	8.40	8.40	0.000
124	4021.70165	73.2	73.1	2.25	8.23	8.23	0.000
125	4023.30195	73.3	73.1	2.25	7.96	7.96	0.000
126	4026.50221	74.0	73.5	2.25	7.79	7.79	0.000
127	4032.90275	73.6	73.3	2.25	7.76	7.76	0.000
128	4045.70319	72.9	73.1	2.25	7.71	7.71	0.000
129	4071.30357	72.6	73.2	2.25	7.65	7.65	0.000
130	4081.66658	73.4	72.9	2.25	7.63	7.63	0.000
131	4081.73385			2.25	7.63	7.63	0.000
132	4081.74000	72.5	73.0	2.25	7.63	7.63	0.000
133	4081.85659	73.0	72.6	1.73	1.72	1.72	0.000
134	4081.96775	73.2	72.9	1.40	0.00	0.00	0.000
135	4082.07901	72.7	73.3	1.21	0.00	0.00	0.000
136	4082.19011	72.8	72.9	1.06	0.00	0.00	0.000
137	4082.30063	73.2	73.0	0.92	0.00	0.00	0.000
138	4082.47000	72.8	73.2	0.78	0.00	0.00	0.000
139	4082.52342	73.8	72.8	0.74	0.00	0.00	0.000
140	4082.63396	73.1	73.3	0.68	0.00	0.00	0.000
141	4082.74528			0.61	0.00	0.00	0.000
142	4082.78589	73.5	73.0	0.60	0.00	0.00	0.000
143	4082.89699	73.4	73.0	0.55	0.00	0.00	0.000
144	4083.00810	73.3	73.4	0.53	0.00	0.00	0.000
145	4083.11976	73.5	72.8	0.51	0.00	0.00	0.000
146	4083.23042	72.9	72.9	0.50	0.00	0.00	0.000
147	4083.34181	73.3	73.1	0.50	0.00	0.00	0.000
148	4083.46000	73.0	73.3	0.50	0.00	0.00	0.000
149	4083.56427	73.1	73.2	0.94	3.24	3.24	0.000

TABLE 29. TEST NO. 19 - MINIBIAXIAL STRESS, SAMPLE
(SHEET 4 OF 6)

150	4083.67483	73.2	73.0	1.38	7.26	7.26	0.000
151	4084.12792			3.01	21.00	21.00	0.000
152	4084.32878	73.2	72.8	3.01	8.40	8.40	0.000
153	4084.72931	73.5	72.9	3.01	8.02	8.02	0.000
154	4085.52965	73.1	73.3	3.01	7.72	7.72	0.000
155	4087.13031	74.4	73.8	3.01	7.47	7.47	0.000
156	4090.33106	74.2	73.5	3.01	7.37	7.37	0.000
157	4096.73148	73.1	73.4	3.01	7.34	7.34	0.000
158	4109.53174	72.8	73.1	3.01	7.34	7.34	0.000
159	4135.13241	72.9	73.0	3.01	7.34	7.34	0.000
160	4146.69191	73.3	73.1	3.01	7.33	7.33	0.000
161	4146.92433			3.01	7.33	7.33	0.000
162	4146.93106			1.85	0.00	0.00	0.000
163	4146.93548			1.80	0.00	0.00	0.000
164	4146.94226			1.78	0.00	0.00	0.000
165	4146.94667			2.35	4.45	4.45	0.000
166	4146.96000			3.96	30.00	30.00	0.000
167	4147.45818	72.9	73.1	3.96	19.24	19.24	0.000
168	4147.85867	72.9	73.1	3.96	18.16	18.16	0.000
169	4148.65890	73.2	73.0	3.96	17.16	17.16	0.000
170	4150.25924	73.4	73.5	3.96	16.08	16.08	0.000
171	4153.45961	73.6	73.3	3.96	15.29	15.29	0.000
172	4159.86051	73.8	73.5	3.96	14.64	14.64	0.000
173	4172.66086	73.9	73.4	3.96	14.12	14.12	0.000
174	4198.26115	73.4	73.3	3.96	13.63	13.63	0.000
175	4223.96355	73.6	73.2	3.96	13.30	13.30	0.000
176	4224.04053			3.96	13.30	13.30	0.000
177	4224.04726			3.95	0.00	0.00	0.000
178	4224.05169			3.94	0.00	0.00	0.000
179	4224.05610			3.93	0.00	0.00	0.000
180	4224.06049			3.92	0.00	0.00	0.000
181	4224.34755	73.3	73.1	3.73	0.00	0.00	0.000
182	4224.54796	73.8	73.1	3.62	0.00	0.00	0.000
183	4224.94817	73.6	73.5	3.46	0.00	0.00	0.000
184	4225.74866	73.3	73.0	3.11	0.00	0.00	0.000
185	4227.34919	73.6	73.3	2.52	0.00	0.00	0.000
186	4230.54950	74.2	73.3	1.65	0.00	0.00	0.000
187	4236.94982	73.6	73.3	0.59	0.00	0.00	0.000
188	4249.75073	73.4	73.6	0.00	0.00	0.00	0.000
189	4275.35104	74.1	73.3	0.00	0.00	0.00	0.000
190	4326.55171	74.9	74.0	0.00	0.00	0.00	0.900
191	4428.95216	75.8	75.2	0.00	0.00	0.00	0.000
192	4633.75293	74.7	73.7	0.00	0.00	0.00	0.000
193	5043.35376	72.9	73.1	0.00	0.00	0.00	0.000
194	5862.55471	75.7	75.5	0.00	0.00	0.00	0.000
195	7500.95494	75.6	75.1	0.00	0.00	0.00	0.000
196	9982.58566	76.2	75.7	0.00	0.00	0.00	0.000
197	9982.70146			0.00	0.00	0.00	0.000
198	9982.70612			0.00	0.00	0.00	0.000
199	9982.71234			0.00	0.00	0.00	0.000
200	9982.71866			0.00	0.00	0.00	0.000
201	9982.72501			1.88	1.41	1.41	0.000
202	9982.73200	76.0	75.8	1.88	0.97	0.97	0.000
203	9983.25743	75.6	75.8	1.55	0.00	0.00	0.000
204	9983.65837	75.8	75.6	1.35	0.00	0.00	0.000
205	9984.45893	75.9	75.7	1.05	0.00	0.00	0.000
206	9986.05982	75.9	75.5	0.75	0.00	0.00	0.000
207	9989.26041	75.6	75.3	0.30	0.00	0.00	0.000
208	9995.66106	76.1	75.9	0.18	0.00	0.00	0.000
209	10008.46150	77.1	76.7	0.18	0.00	0.00	0.000

TABLE 29. TEST NO. 19 - MINIBIAXIAL STRESS, SAMPLE
(SHEET 5 OF 6)

210	10013.95679	76.7	76.9	0.18	0.00	0.00	0.000
211	10014.02390			0.18	0.00	0.00	0.000
212	10014.02937			0.18	0.00	0.00	0.000
213	10014.03556			0.18	0.00	0.00	0.000
214	10014.04185			0.18	0.00	0.00	0.000
215	10014.04814			0.18	0.00	0.00	0.000
216	10014.33226	76.8	77.1	0.18	0.00	0.00	0.000
217	10014.53265	77.2	77.0	0.18	0.00	0.00	0.000
218	10014.93333	76.8	77.1	0.18	0.00	0.00	0.000
219	10015.73354	77.5	77.5	0.18	0.00	0.00	0.000
220	10017.33388	77.7	77.8	0.18	0.00	0.00	0.000
221	10020.53420	78.3	77.8	0.18	0.00	0.00	0.000
222	10026.93442	77.6	77.4	0.18	0.00	0.00	0.000
223	10039.73473	78.1	77.6	0.18	0.00	0.00	0.000
224	10045.97967	78.5	77.4	0.18	0.00	0.00	0.000
225	10046.06500			0.18	0.00	0.00	0.000
226	10046.06681			0.18	0.00	0.00	0.000
227	10046.07122			0.18	0.00	0.00	0.000
228	10046.07562			0.30	0.50	0.50	0.000
229	10046.08003			0.99	2.15	2.15	0.000
230	10046.08446			1.62	3.82	3.82	0.000
231	10046.08800			0.93	0.00	0.00	0.000
232	10046.09127			0.92	0.00	0.00	0.000
233	10046.09566			0.91	0.00	0.00	0.000
234	10046.10445			0.90	0.00	0.00	0.000
235	10046.42716	78.0	76.9	0.86	0.00	0.00	0.000
236	10046.62756	77.9	76.9	0.82	0.00	0.00	0.000
237	10047.02811	78.0	76.5	0.76	0.00	0.00	0.000
238	10047.82903	77.6	76.0	0.64	0.00	0.00	0.000
239	10049.42968	77.4	75.6	0.44	0.00	0.00	0.000
240	10052.63057	76.5	75.5	0.23	0.00	0.00	0.000
241	10059.03137	76.4	76.3	0.18	0.00	0.00	0.000
242	10071.83166	77.5	77.5	0.18	0.00	0.00	0.000
243	10072.15161	77.3	77.5	0.18	0.00	0.00	0.000
244	10072.23891			0.18	0.00	0.00	0.000
245	10072.24482			0.18	0.00	0.00	0.000
246	10072.24924			0.18	0.00	0.00	0.000
247	10072.25600			0.93	0.51	0.51	0.000
248	10072.25807			1.35	3.13	3.13	0.000
249	10072.26249			2.00	12.98	12.98	0.000
250	10072.26693			2.78	26.13	26.13	0.000
251	10072.27136			3.42	39.26	39.26	0.000
252	10072.27820			2.15	6.43	6.43	0.000
253	10072.28300			1.25	0.00	0.00	0.000
254	10072.28705			1.24	0.00	0.00	0.000
255	10072.29145			1.23	0.00	0.00	0.000
256	10072.29582			1.23	0.00	0.00	0.000
257	10072.30021			1.22	0.00	0.00	0.000
258	10072.57191	77.3	77.6	0.93	0.00	0.00	0.000
259	10072.77268	77.8	77.5	0.85	0.00	0.00	0.000
260	10073.17346	77.9	77.6	0.76	0.00	0.00	0.000
261	10073.97405	77.9	77.7	0.70	0.00	0.00	0.000
262	10075.57456	78.9	78.1	0.70	0.00	0.00	0.000
263	10078.77486	78.2	77.8	0.70	0.00	0.00	0.000
264	10085.17571	78.1	77.7	0.70	0.00	0.00	0.000
265	10097.97639	76.6	75.5	0.70	0.00	0.00	0.000
266	10104.41636	76.8	76.8	0.70	0.00	0.00	0.000
267	10104.49450			0.70	0.00	0.00	0.000
268	10104.49732			0.70	0.00	0.00	0.000
269	10104.50174			0.70	0.00	0.00	0.000

TABLE 29. TEST NO. 19 - MINIBIAXIAL STRESS, SAMPLE (SHEET 6 OF 6)

270	10104.50900			0.70	0.00	0.00	0.000
271	10104.51057			0.95	5.24	5.24	0.000
272	10104.51501			1.70	16.42	16.42	0.000
273	10104.51946			2.40	29.90	29.90	0.000
274	10104.52391			3.10	43.24	43.24	0.000
275	10104.52800			3.74	55.50	55.50	0.000
276	10104.53517			2.60	18.73	18.73	0.000
277	10104.53958			1.90	7.04	7.04	0.000
278	10104.54399			1.13	0.61	0.61	0.000
279	10104.54840			1.13	0.00	0.00	0.000
280	10104.55281			1.12	0.00	0.00	0.000
281	10104.55723			1.12	0.00	0.00	0.000
282	10104.56161			1.11	0.00	0.00	0.000
283	10104.56601			1.11	0.00	0.00	0.000
284	10104.86312	77.0	76.7	0.90	0.00	0.00	0.000
285	10105.46396	77.0	77.0	0.70	0.00	0.00	0.000
286	10106.26492	77.3	76.9	0.60	0.00	0.00	0.000
287	10107.86525	78.1	77.4	0.60	0.00	0.00	0.000
288	10111.06546	77.5	77.2	0.60	0.00	0.00	0.000
289	10117.46576	77.2	77.4	0.60	0.00	0.00	0.000
290	10130.26605	78.2	78.0	0.60	0.00	0.00	0.000
291	10137.99869	78.8	76.6	0.60	0.00	0.00	0.000
292	10138.18300			0.60	0.00	0.00	0.000
293	10138.18910			0.60	0.00	0.00	0.000
294	10138.19351			0.60	0.00	0.00	0.000
295	10138.19700			0.60	0.00	0.00	0.000
296	10138.20234			1.29	9.84	9.84	0.000
297	10138.20674			1.85	21.96	21.96	0.000
298	10138.21116			2.40	34.42	34.42	0.000
299	10138.21558			2.95	47.10	47.10	0.000
300	10138.22001			3.53	60.96	60.96	0.000
301	10138.22443			4.10	73.07	73.07	0.000
302	10138.22800			4.54	82.50	82.50	0.000
303	10138.57723	78.2	76.4	4.54	36.47	36.47	0.000
304	10138.77746	77.9	76.2	4.54	34.09	34.09	0.000
305	10139.17768	77.9	76.0	4.54	31.60	31.60	0.000
306	10139.97795	77.7	75.8	4.54	29.19	29.19	0.000
307	10141.57841	77.6	75.8	4.54	26.75	26.75	0.000
308	10144.77931	77.2	76.1	4.54	24.69	24.69	0.000
309	10151.18012	76.3	77.1	4.54	22.94	22.94	0.000
310	10163.98056	77.0	77.2	4.54	21.64	21.64	0.000
311	10189.58086	76.4	76.0	4.54	20.34	20.34	0.000
312	10191.26333	76.3	76.4	4.54	20.26	20.26	0.000
313	10191.32941			4.54	20.26	20.26	0.000
314	10191.33616			4.43	4.77	4.77	0.000
315	10191.34059			4.42	0.00	0.00	0.000
316	10191.34499			4.41	0.00	0.00	0.000
317	10191.34940			4.41	0.00	0.00	0.000
318	10191.35378			4.40	0.00	0.00	0.000
319	10191.35817			4.40	0.00	0.00	0.000
320	10191.36256			4.40	0.00	0.00	0.000
321	10191.36696			4.39	0.00	0.00	0.000
322	10191.37136			4.39	0.00	0.00	0.000
323	10191.37577			4.39	0.00	0.00	0.000
324	10191.62483	76.5	76.4	4.36	0.00	0.00	0.000
325	10208.00000			1.70	0.00	0.00	0.000
326	10221.00000			0.70	0.00	0.00	0.000

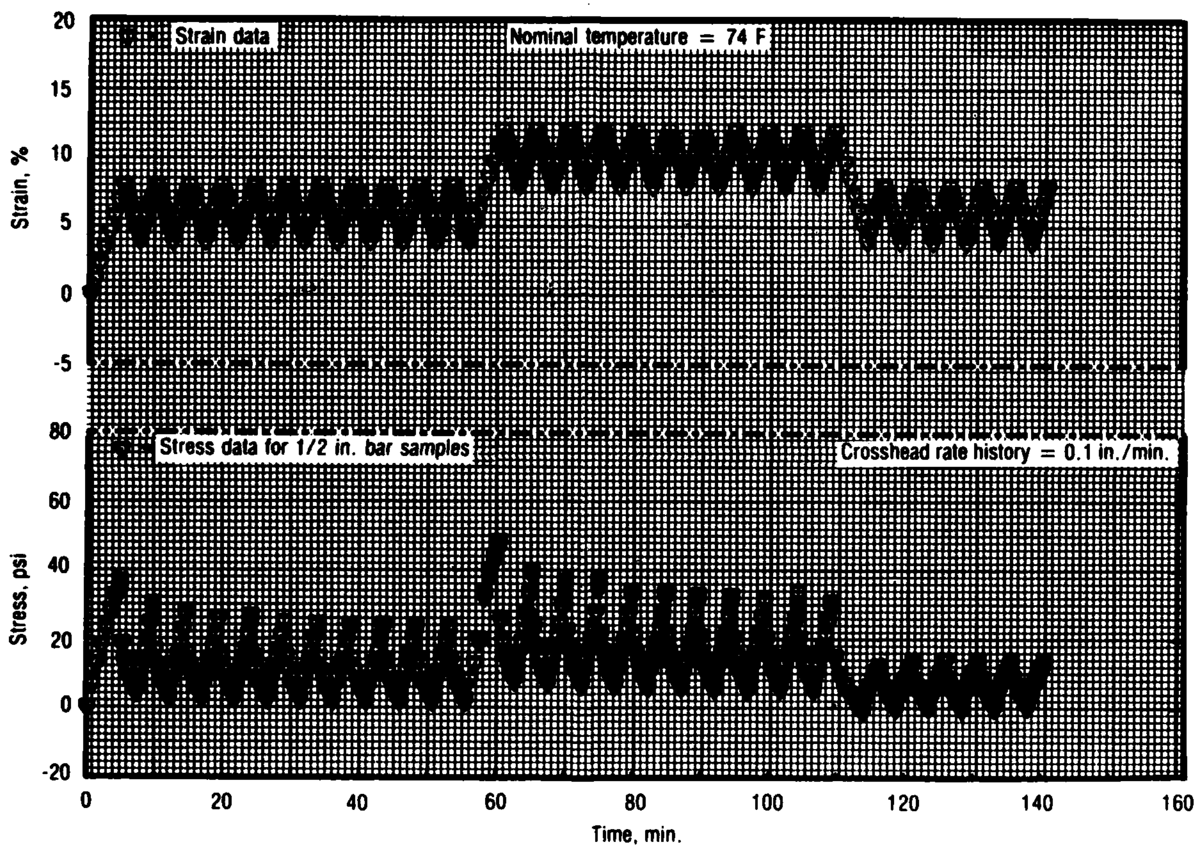


Figure 59. Test No. 20 - Stress While Cycling for UTP-19,360B-400/1777 for Complete Test

28821

TABLE 30. 1/2-IN. BAR STRESS WHILE CYCLING (SHEET 1 OF 15)

PROPELLANT: UTP 19360B 400/1777
REQUESTOR: Carlton Francis
WOR: 2742-400-0000

DATE: 1/14/81
OPERATOR: JWD

DEFINITIONS:
Time = Time From Start of Test (min)
σ = Stress (psi)
ε = Strain (%)
T(air) = Test Air Temperature (F)
T(prop) = Test Propellant Temperature (F)

RELATIONSHIPS:
σ = Force/Area
ε = Sample Extension/Length

NOMINAL VALUES:
Test Temp = 74 F
Gage Length = 6.00 in
Nom. Strain = 8,4,12,8,4,8,0 %
XHD Rate = .1 in/min

CALIBRATION DATA:

Cal Wt = 10.0 lbs		SAMPLE 1	SAMPLE 2	SAMPLE 3
Load Cal	(lbs/volts)	29.776	29.679	29.966
Offset	(volts)	0.080	-0.012	0.036
Pot Cal	(in/volts) =	-0.393		
Temp	(F) =	77.2		

AREAS (sq in):	0.253	0.252	0.252

LOAD DIFFLECTION DATA (volts):

SET	Time	Pot Disp	1	2	3
1	0.00500	-0.001	0.079	-0.014	0.035
2	0.69073	-0.176	0.137	0.047	0.096
3	1.37645	-0.351	0.187	0.097	0.146
4	2.06274	-0.525	0.232	0.142	0.192
5	2.74785	-0.700	0.275	0.183	0.236
6	3.43369	-0.875	0.316	0.223	0.276
7	4.11977	-1.050	0.353	0.257	0.314
8	4.78160	-1.218	0.390	0.289	0.350
9	4.79196	-1.216	0.376	0.275	0.333
10	5.13504	-1.131	0.240	0.141	0.194
11	5.47779	-1.045	0.199	0.100	0.152
12	5.82050	-0.958	0.174	0.077	0.127
13	6.16369	-0.871	0.157	0.060	0.109
14	6.50613	-0.784	0.143	0.044	0.095
15	6.84910	-0.696	0.130	0.035	0.083
16	7.19247	-0.608	0.118	0.026	0.070
17	7.23347	-0.606	0.123	0.028	0.076
18	7.57631	-0.692	0.155	0.059	0.108
19	7.91977	-0.781	0.177	0.082	0.131
20	8.26250	-0.868	0.198	0.105	0.152
21	8.60490	-0.955	0.221	0.125	0.175
22	8.94769	-1.042	0.249	0.154	0.204
23	9.29071	-1.129	0.290	0.193	0.246
24	9.62484	-1.214	0.329	0.231	0.286
25	9.63515	-1.212	0.338	0.241	0.294
26	9.97822	-1.126	0.224	0.127	0.178
27	10.32119	-1.040	0.186	0.089	0.139
28	10.66380	-0.952	0.163	0.069	0.116
29	11.00693	-0.866	0.147	0.053	0.100
30	11.34940	-0.778	0.134	0.039	0.086

TABLE 30. 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 2 OF 15)

31	11.69215	-0.690	0.122	0.025	0.075
32	12.05490	-0.598	0.109	0.010	0.062
33	12.39773	-0.691	0.147	0.054	0.100
34	12.74051	-0.779	0.168	0.074	0.121
35	13.08376	-0.867	0.188	0.092	0.142
36	13.42624	-0.954	0.209	0.114	0.164
37	13.76949	-1.041	0.236	0.141	0.191
38	14.11250	-1.128	0.272	0.177	0.229
39	14.47511	-1.220	0.310	0.215	0.269
40	14.81803	-1.124	0.215	0.121	0.170
41	15.16115	-1.038	0.180	0.085	0.134
42	15.50364	-0.951	0.158	0.064	0.112
43	15.84717	-0.863	0.142	0.049	0.096
44	16.18947	-0.776	0.129	0.036	0.082
45	16.53245	-0.688	0.118	0.024	0.071
46	16.89455	-0.595	0.106	0.012	0.059
47	17.23753	-0.687	0.142	0.048	0.095
48	17.58038	-0.775	0.163	0.072	0.116
49	17.92369	-0.863	0.181	0.090	0.136
50	18.26606	-0.950	0.203	0.108	0.157
51	18.60919	-1.037	0.227	0.133	0.183
52	18.95166	-1.124	0.263	0.168	0.218
53	19.31323	-1.216	0.300	0.205	0.255
54	19.65618	-1.117	0.209	0.116	0.163
55	19.99925	-1.030	0.175	0.082	0.129
56	20.34244	-0.943	0.154	0.062	0.108
57	20.68484	-0.856	0.139	0.048	0.092
58	21.02751	-0.769	0.126	0.035	0.079
59	21.37077	-0.681	0.114	0.022	0.068
60	21.68537	-0.600	0.104	0.010	0.057
61	21.69569	-0.602	0.107	0.017	0.061
62	22.03863	-0.688	0.138	0.046	0.093
63	22.38164	-0.776	0.159	0.067	0.114
64	22.72419	-0.863	0.178	0.086	0.134
65	23.06710	-0.950	0.199	0.105	0.155
66	23.41033	-1.038	0.224	0.131	0.180
67	23.75287	-1.125	0.257	0.162	0.215
68	24.08557	-1.209	0.290	0.192	0.248
69	24.09591	-1.207	0.307	0.210	0.264
70	24.43905	-1.121	0.208	0.114	0.164
71	24.78195	-1.035	0.174	0.083	0.129
72	25.12460	-0.948	0.153	0.057	0.108
73	25.46800	-0.861	0.137	0.041	0.092
74	25.81034	-0.773	0.125	0.033	0.079
75	26.15294	-0.686	0.113	0.022	0.067
76	26.51526	-0.593	0.101	0.012	0.055
77	26.85828	-0.690	0.137	0.045	0.092
78	27.20153	-0.777	0.158	0.066	0.113
79	27.54412	-0.865	0.177	0.087	0.132
80	27.88735	-0.953	0.197	0.108	0.153
81	28.22959	-1.040	0.221	0.127	0.178
82	28.57255	-1.127	0.255	0.163	0.212
83	28.93549	-1.219	0.291	0.200	0.249
84	29.27824	-1.128	0.208	0.115	0.164
85	29.62146	-1.041	0.174	0.081	0.129
86	29.96399	-0.954	0.153	0.060	0.107
87	30.30720	-0.867	0.137	0.045	0.092
88	30.64994	-0.780	0.124	0.029	0.079
89	30.99282	-0.692	0.113	0.019	0.067
90	31.33502	-0.600	0.101	0.009	0.055

TABLE 30. 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 3 OF 15)

91	31.69814	-0.691	0.135	0.043	0.090
92	32.04118	-0.778	0.155	0.061	0.111
93	32.38396	-0.866	0.175	0.081	0.130
94	32.72699	-0.954	0.195	0.101	0.151
95	33.06944	-1.040	0.219	0.125	0.175
96	33.41208	-1.128	0.251	0.157	0.209
97	33.77510	-1.220	0.286	0.191	0.245
98	34.11826	-1.127	0.206	0.111	0.161
99	34.46080	-1.040	0.172	0.078	0.127
100	34.80374	-0.953	0.151	0.059	0.106
101	35.14670	-0.866	0.136	0.043	0.090
102	35.48994	-0.779	0.123	0.029	0.077
103	35.83240	-0.691	0.111	0.019	0.066
104	36.19523	-0.598	0.099	0.008	0.054
105	36.53865	-0.692	0.134	0.041	0.089
106	36.88115	-0.779	0.154	0.063	0.110
107	37.22373	-0.867	0.174	0.079	0.129
108	37.56681	-0.954	0.194	0.098	0.149
109	37.90955	-1.041	0.217	0.124	0.174
110	38.25241	-1.128	0.250	0.155	0.207
111	38.61549	-1.220	0.285	0.188	0.242
112	38.95827	-1.128	0.204	0.109	0.160
113	39.30125	-1.041	0.171	0.078	0.126
114	39.64460	-0.954	0.150	0.058	0.105
115	39.98684	-0.867	0.135	0.040	0.090
116	40.33004	-0.779	0.122	0.030	0.077
117	40.67266	-0.692	0.111	0.019	0.065
118	41.03509	-0.599	0.099	0.008	0.053
119	41.37791	-0.693	0.134	0.040	0.089
120	41.72090	-0.781	0.154	0.060	0.109
121	42.06418	-0.869	0.173	0.077	0.129
122	42.40658	-0.956	0.194	0.099	0.149
123	42.74937	-1.043	0.218	0.125	0.174
124	43.09250	-1.130	0.250	0.154	0.207
125	43.45380	-1.222	0.284	0.184	0.243
126	43.79670	-1.123	0.202	0.105	0.157
127	44.13952	-1.037	0.170	0.074	0.124
128	44.48292	-0.949	0.149	0.055	0.104
129	44.82580	-0.862	0.134	0.040	0.088
130	45.16797	-0.775	0.121	0.029	0.075
131	45.51093	-0.687	0.110	0.017	0.063
132	45.84334	-0.602	0.099	0.006	0.052

TABLE 30. 1/2-IN. BAR STRESS WHILE CYCLING (SHEET 4 OF 15)

133	45.85361	-0.603	0.101	0.010	0.056
134	46.19653	-0.690	0.133	0.040	0.087
135	46.53977	-0.777	0.153	0.056	0.108
136	46.88214	-0.865	0.172	0.077	0.127
137	47.22508	-0.952	0.192	0.097	0.147
138	47.56827	-1.040	0.216	0.121	0.172
139	47.91093	-1.127	0.248	0.152	0.204
140	48.27385	-1.219	0.282	0.185	0.238
141	48.61673	-1.127	0.203	0.107	0.158
142	48.95995	-1.040	0.170	0.076	0.125
143	49.30255	-0.953	0.149	0.057	0.104
144	49.64519	-0.866	0.134	0.039	0.088
145	49.98835	-0.778	0.121	0.026	0.075
146	50.33095	-0.691	0.109	0.015	0.063
147	50.69400	-0.598	0.097	0.004	0.051
148	51.03687	-0.690	0.132	0.036	0.087
149	51.37976	-0.777	0.153	0.058	0.107
150	51.72260	-0.865	0.172	0.075	0.126
151	52.06615	-0.953	0.191	0.096	0.146
152	52.40829	-1.040	0.215	0.119	0.170
153	52.75131	-1.127	0.247	0.149	0.203
154	53.11390	-1.219	0.280	0.180	0.237
155	53.45673	-1.127	0.202	0.105	0.157
156	53.80002	-1.040	0.169	0.071	0.124
157	54.14286	-0.953	0.149	0.053	0.103
158	54.48586	-0.866	0.133	0.037	0.087
159	54.82875	-0.778	0.120	0.028	0.074
160	55.17092	-0.691	0.108	0.015	0.063
161	55.51443	-0.603	0.097	0.003	0.052
162	55.55532	-0.607	0.103	0.009	0.058
163	56.24100	-0.781	0.152	0.057	0.107
164	56.92671	-0.957	0.191	0.096	0.145
165	57.61259	-1.131	0.246	0.150	0.202
166	58.29818	-1.304	0.358	0.262	0.318
167	58.98386	-1.479	0.413	0.314	0.373
168	59.66994	-1.657	0.450	0.349	0.409
169	60.37566	-1.841	0.487	0.385	0.446
170	60.71865	-1.748	0.301	0.204	0.257
171	61.06170	-1.659	0.247	0.151	0.202
172	61.40450	-1.570	0.216	0.120	0.170
173	61.74770	-1.482	0.193	0.098	0.148
174	62.09027	-1.394	0.177	0.080	0.132
175	62.43270	-1.307	0.163	0.067	0.118
176	62.77585	-1.219	0.150	0.054	0.105
177	62.81698	-1.220	0.158	0.060	0.113
178	63.16006	-1.307	0.192	0.097	0.148
179	63.50262	-1.394	0.218	0.125	0.173
180	63.84548	-1.482	0.244	0.149	0.199
181	64.18884	-1.570	0.273	0.179	0.229
182	64.53186	-1.660	0.311	0.213	0.267
183	64.87410	-1.749	0.363	0.264	0.320
184	65.23684	-1.842	0.418	0.317	0.376
185	65.58008	-1.750	0.283	0.183	0.239
186	65.92320	-1.662	0.234	0.137	0.189
187	66.26555	-1.573	0.204	0.109	0.159
188	66.60820	-1.485	0.185	0.089	0.139
189	66.95145	-1.397	0.170	0.070	0.122
190	67.29457	-1.309	0.157	0.062	0.110
191	67.63680	-1.221	0.145	0.051	0.098
192	67.67079	-1.212	0.144	0.049	0.097

TABLE 30. 1/2-IN. BAR STRESS WHILE CYCLING (SHEET 5 OF 15)

193	67.68110	-1.214	0.146	0.050	0.100
194	68.02414	-1.302	0.182	0.087	0.136
195	68.36718	-1.389	0.207	0.110	0.160
196	68.70974	-1.476	0.231	0.135	0.184
197	69.05241	-1.565	0.257	0.161	0.211
198	69.39534	-1.654	0.290	0.193	0.244
199	69.73815	-1.743	0.335	0.237	0.290
200	70.08162	-1.831	0.380	0.281	0.332
201	70.12405	-1.835	0.396	0.293	0.349
202	70.46712	-1.746	0.272	0.173	0.227
203	70.81010	-1.658	0.227	0.130	0.180
204	71.15259	-1.569	0.199	0.103	0.152
205	71.49607	-1.481	0.180	0.084	0.133
206	71.83895	-1.393	0.164	0.070	0.118
207	72.18119	-1.306	0.152	0.058	0.105
208	72.52425	-1.217	0.142	0.046	0.094
209	72.57239	-1.204	0.140	0.045	0.092
210	72.58267	-1.207	0.142	0.046	0.096
211	72.92575	-1.294	0.177	0.079	0.130
212	73.26850	-1.381	0.200	0.106	0.154
213	73.61140	-1.468	0.223	0.127	0.177
214	73.95402	-1.558	0.248	0.149	0.202
215	74.29696	-1.646	0.278	0.178	0.233
216	74.64032	-1.734	0.319	0.224	0.275
217	74.98262	-1.823	0.385	0.282	0.342
218	75.03589	-1.837	0.395	0.291	0.352
219	75.04620	-1.836	0.391	0.286	0.345
220	75.38914	-1.748	0.268	0.171	0.222
221	75.73205	-1.660	0.223	0.127	0.177
222	76.07490	-1.570	0.196	0.102	0.150
223	76.41758	-1.482	0.177	0.080	0.131
224	76.76115	-1.394	0.162	0.066	0.115
225	77.10362	-1.307	0.150	0.055	0.103
226	77.44610	-1.219	0.138	0.043	0.091
227	77.48795	-1.218	0.143	0.050	0.096
228	77.83076	-1.305	0.176	0.078	0.130
229	78.17422	-1.392	0.197	0.105	0.153
230	78.51643	-1.480	0.222	0.126	0.175
231	78.85979	-1.569	0.247	0.151	0.201
232	79.20236	-1.657	0.278	0.184	0.233
233	79.54500	-1.746	0.320	0.223	0.276
234	79.88815	-1.834	0.362	0.262	0.319
235	79.92850	-1.832	0.371	0.269	0.325
236	80.27202	-1.744	0.262	0.164	0.216
237	80.61480	-1.656	0.220	0.123	0.173
238	80.95704	-1.567	0.194	0.098	0.147
239	81.29985	-1.478	0.175	0.079	0.128
240	81.64339	-1.391	0.160	0.063	0.112
241	81.98627	-1.302	0.147	0.051	0.100
242	82.34858	-1.209	0.134	0.038	0.087
243	82.69210	-1.308	0.174	0.079	0.128
244	83.03434	-1.396	0.198	0.101	0.151
245	83.37713	-1.483	0.220	0.122	0.174
246	83.72000	-1.572	0.245	0.150	0.199
247	84.06339	-1.661	0.276	0.177	0.230
248	84.40590	-1.748	0.318	0.217	0.274
249	84.76873	-1.842	0.362	0.259	0.320
250	85.11190	-1.750	0.263	0.162	0.217
251	85.45476	-1.661	0.220	0.120	0.173
252	85.79725	-1.572	0.193	0.095	0.146
253	86.14009	-1.484	0.174	0.075	0.127

TABLE 30. 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 6 OF 15)

254	86.48366	-1.396	0.159	0.063	0.112
255	86.82636	-1.308	0.147	0.051	0.099
256	87.16879	-1.221	0.134	0.038	0.087
257	87.21110	-1.223	0.141	0.046	0.095
258	87.55424	-1.310	0.173	0.075	0.126
259	87.89750	-1.398	0.196	0.098	0.149
260	88.24031	-1.486	0.219	0.121	0.172
261	88.58294	-1.574	0.243	0.143	0.197
262	88.92570	-1.662	0.274	0.174	0.228
263	89.26830	-1.751	0.316	0.213	0.271
264	89.63106	-1.844	0.361	0.255	0.316
265	89.97389	-1.749	0.260	0.160	0.214
266	90.31715	-1.660	0.217	0.119	0.171
267	90.65963	-1.571	0.192	0.088	0.144
268	91.00313	-1.483	0.173	0.073	0.126
269	91.34572	-1.395	0.159	0.060	0.110
270	91.68815	-1.308	0.145	0.048	0.098
271	92.03160	-1.220	0.132	0.035	0.086
272	92.07254	-1.217	0.138	0.039	0.091
273	92.41599	-1.304	0.171	0.071	0.124
274	92.75875	-1.392	0.194	0.093	0.146
275	93.10115	-1.479	0.215	0.115	0.169
276	93.44418	-1.569	0.240	0.139	0.193
277	93.78690	-1.656	0.269	0.168	0.223
278	94.13026	-1.745	0.309	0.208	0.264
279	94.47266	-1.834	0.349	0.248	0.304
280	94.51315	-1.832	0.359	0.254	0.312
281	94.85646	-1.744	0.256	0.156	0.209
282	95.19885	-1.655	0.215	0.115	0.168
283	95.54230	-1.566	0.189	0.092	0.142
284	95.88524	-1.478	0.171	0.071	0.124
285	96.22789	-1.391	0.156	0.057	0.109
286	96.57071	-1.302	0.144	0.044	0.097
287	96.93255	-1.209	0.130	0.031	0.084
288	97.27567	-1.304	0.169	0.072	0.123
289	97.61854	-1.392	0.192	0.091	0.145
290	97.96165	-1.479	0.214	0.116	0.167
291	98.30405	-1.568	0.237	0.139	0.191
292	98.64725	-1.656	0.266	0.168	0.221
293	98.98996	-1.745	0.306	0.208	0.261
294	99.35204	-1.839	0.348	0.250	0.304
295	99.69545	-1.747	0.256	0.155	0.209
296	100.03771	-1.658	0.215	0.116	0.168
297	100.38059	-1.569	0.189	0.087	0.142
298	100.72345	-1.481	0.170	0.076	0.123
299	101.06668	-1.393	0.156	0.059	0.109
300	101.40969	-1.305	0.143	0.049	0.096
301	101.75201	-1.217	0.130	0.039	0.084
302	101.79253	-1.214	0.135	0.040	0.089
303	102.13579	-1.302	0.168	0.071	0.121
304	102.47835	-1.389	0.190	0.095	0.143
305	102.82107	-1.477	0.212	0.117	0.165
306	103.16400	-1.566	0.235	0.137	0.189
307	103.50675	-1.654	0.264	0.166	0.217
308	103.84985	-1.742	0.302	0.203	0.257
309	104.19245	-1.831	0.340	0.240	0.297
310	104.23299	-1.838	0.366	0.264	0.321
311	104.57618	-1.750	0.256	0.158	0.209
312	104.91885	-1.662	0.214	0.118	0.167
313	105.26146	-1.573	0.188	0.092	0.142

TABLE 30. 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 7 OF 15)

314	105.60444	-1.485	0.170	0.073	0.123
315	105.94774	-1.397	0.156	0.061	0.108
316	106.29054	-1.309	0.143	0.046	0.096
317	106.63322	-1.221	0.130	0.031	0.083
318	106.67593	-1.216	0.134	0.035	0.088
319	107.01948	-1.304	0.167	0.070	0.121
320	107.36178	-1.392	0.189	0.091	0.142
321	107.70476	-1.479	0.211	0.115	0.164
322	108.04778	-1.569	0.234	0.136	0.188
323	108.39058	-1.655	0.263	0.163	0.217
324	108.73310	-1.745	0.301	0.201	0.256
325	109.07600	-1.834	0.339	0.238	0.295
326	109.11885	-1.830	0.346	0.240	0.299
327	109.80496	-1.653	0.211	0.111	0.164
328	110.49023	-1.476	0.168	0.070	0.121
329	111.17603	-1.300	0.142	0.047	0.094
330	111.86238	-1.127	0.121	0.026	0.074
331	112.54743	-0.953	0.106	0.011	0.058
332	113.23370	-0.776	0.093	-0.005	0.045
333	113.90282	-0.605	0.080	-0.012	0.036
334	113.91317	-0.607	0.080	-0.012	0.036
335	114.25626	-0.694	0.109	0.013	0.062
336	114.59879	-0.781	0.124	0.028	0.078
337	114.94216	-0.869	0.138	0.044	0.092
338	115.28495	-0.956	0.151	0.055	0.105
339	115.62779	-1.043	0.164	0.065	0.117
340	115.97046	-1.131	0.177	0.076	0.130
341	116.30202	-1.216	0.189	0.087	0.142
342	116.31235	-1.213	0.185	0.088	0.139
343	116.65557	-1.127	0.151	0.052	0.104
344	116.99854	-1.040	0.134	0.039	0.087
345	117.34157	-0.953	0.122	0.027	0.075
346	117.68433	-0.866	0.111	0.013	0.064
347	118.02685	-0.778	0.102	0.007	0.054
348	118.36969	-0.691	0.093	-0.004	0.045
349	118.70330	-0.606	0.084	-0.013	0.037
350	118.71368	-0.607	0.086	-0.012	0.039
351	119.05659	-0.693	0.113	0.015	0.067
352	119.40001	-0.780	0.130	0.033	0.083
353	119.74239	-0.868	0.143	0.047	0.097
354	120.08500	-0.955	0.156	0.062	0.110
355	120.42846	-1.043	0.170	0.072	0.123
356	120.77066	-1.130	0.183	0.083	0.136
357	121.13370	-1.222	0.197	0.094	0.150
358	121.47650	-1.123	0.154	0.055	0.108
359	121.81948	-1.036	0.138	0.037	0.090
360	122.16266	-0.949	0.125	0.025	0.077
361	122.50503	-0.862	0.113	0.017	0.066
362	122.84802	-0.774	0.103	0.005	0.056
363	123.19144	-0.686	0.094	-0.001	0.047
364	123.51307	-0.604	0.086	-0.006	0.038
365	123.52342	-0.606	0.087	-0.010	0.041
366	123.86648	-0.692	0.115	0.017	0.068
367	124.20911	-0.780	0.132	0.034	0.085
368	124.55249	-0.868	0.146	0.046	0.099
369	124.89486	-0.955	0.159	0.060	0.112
370	125.23816	-1.042	0.172	0.074	0.125
371	125.58055	-1.130	0.185	0.090	0.139
372	125.94280	-1.222	0.200	0.106	0.153
373	126.28570	-1.125	0.158	0.059	0.110

TABLE 30. 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 8 OF 15)

374	126.62850	-1.038	0.140	0.042	0.092
375	126.97140	-0.951	0.126	0.028	0.079
376	127.31448	-0.863	0.115	0.019	0.067
377	127.65706	-0.775	0.105	0.007	0.057
378	128.00000	-0.688	0.095	-0.004	0.048
379	128.36300	-0.595	0.085	-0.016	0.038
380	128.70626	-0.692	0.116	0.018	0.069
381	129.04861	-0.780	0.133	0.033	0.086
382	129.39209	-0.868	0.147	0.049	0.100
383	129.73432	-0.955	0.160	0.058	0.114
384	130.07760	-1.042	0.173	0.073	0.127
385	130.42069	-1.129	0.187	0.087	0.140
386	130.75319	-1.214	0.200	0.099	0.153
387	130.76350	-1.212	0.198	0.095	0.151
388	131.10642	-1.126	0.159	0.059	0.113
389	131.44955	-1.039	0.141	0.040	0.094
390	131.79233	-0.952	0.127	0.030	0.080
391	132.13514	-0.865	0.115	0.018	0.068
392	132.47798	-0.778	0.105	0.010	0.059
393	132.82093	-0.690	0.096	-0.001	0.049
394	133.15012	-0.606	0.087	-0.012	0.039
395	133.16050	-0.607	0.089	-0.009	0.042
396	133.50340	-0.693	0.115	0.019	0.069
397	133.84667	-0.781	0.132	0.034	0.086
398	134.18950	-0.869	0.147	0.049	0.101
399	134.53217	-0.956	0.159	0.063	0.114
400	134.87468	-1.043	0.174	0.077	0.127
401	135.21799	-1.130	0.188	0.088	0.141
402	135.54712	-1.214	0.201	0.099	0.154
403	135.55744	-1.212	0.199	0.099	0.152
404	135.90052	-1.126	0.160	0.062	0.113
405	136.24318	-1.040	0.141	0.046	0.095
406	136.58615	-0.952	0.127	0.031	0.080
407	136.92950	-0.866	0.115	0.019	0.069
408	137.27200	-0.778	0.105	0.010	0.058
409	137.61480	-0.690	0.096	0.000	0.049
410	137.95777	-0.602	0.086	-0.009	0.039
411	137.99948	-0.599	0.088	-0.007	0.042
412	138.34275	-0.685	0.115	0.020	0.069
413	138.68513	-0.772	0.132	0.031	0.085
414	139.02861	-0.860	0.146	0.045	0.100
415	139.37078	-0.947	0.160	0.055	0.113
416	139.71382	-1.035	0.172	0.071	0.127
417	140.05702	-1.122	0.186	0.084	0.140
418	140.39932	-1.208	0.201	0.097	0.155

TABLE 30. 1/2-IN. BAR STRESS WHILE CYCLING (SHEET 9 OF 15)

STRESS DATA (psi):

SET	Time	T(prop)	T(air)	Strain	SAMPLE 1	SAMPLE 2	SAMPLE 3	Avg	St Dev
1	0.00500	77.2	76.3	0.01	-0.14	-0.19	-0.11	-0.15	0.028
2	0.69073	76.9	76.0	1.15	6.67	6.92	7.08	6.89	0.145
3	1.37645	76.5	76.1	2.30	12.61	12.85	13.01	12.82	0.142
4	2.06274	76.6	76.1	3.44	17.97	18.16	18.47	18.20	0.179
5	2.74785	76.3	76.1	4.59	23.01	22.92	23.63	23.19	0.274
6	3.43369	76.6	75.8	5.74	27.83	27.65	28.45	27.98	0.294
7	4.11977	76.2	76.0	6.88	32.25	31.62	32.90	32.25	0.455
8	4.78160			7.98	36.51	35.44	37.20	36.38	0.628
9	4.79196	76.2	76.0	7.97	34.85	33.75	35.18	34.59	0.526
10	5.13504	76.3	75.9	7.41	18.87	18.06	18.72	18.55	0.304
11	5.47779	76.2	76.0	6.85	14.06	13.23	13.67	13.65	0.292
12	5.82050	76.3	76.0	6.27	11.11	10.47	10.71	10.76	0.228
13	6.16369	76.2	75.9	5.71	9.03	8.49	8.61	8.71	0.200
14	6.50613	76.2	75.9	5.13	7.37	6.65	6.92	6.98	0.258
15	6.84910	76.3	76.0	4.56	5.95	5.58	5.48	5.67	0.175
16	7.19247			3.98	4.53	4.50	4.04	4.36	0.194
17	7.23347	76.2	76.0	3.97	5.10	4.75	4.69	4.85	0.158
18	7.57631	76.3	76.0	4.54	8.87	8.35	8.52	8.58	0.188
19	7.91977	76.2	76.0	5.11	11.45	11.02	11.17	11.21	0.154
20	8.26250	76.2	75.9	5.69	13.97	13.78	13.69	13.82	0.100
21	8.60490	76.3	76.1	6.26	16.60	16.18	16.51	16.43	0.156
22	8.94769	76.4	75.9	6.83	19.95	19.54	19.95	19.81	0.168
23	9.29071	76.3	76.0	7.40	24.74	24.11	24.86	24.57	0.285
24	9.62484			7.95	29.40	28.57	29.65	29.21	0.401
25	9.63515	76.2	75.9	7.94	30.45	29.73	30.57	30.25	0.324
26	9.97822	76.1	76.0	7.38	16.94	16.35	16.78	16.69	0.214
27	10.32119	76.1	76.0	6.81	12.53	11.86	12.23	12.21	0.235
28	10.66380	76.4	76.0	6.24	9.83	9.58	9.50	9.64	0.123
29	11.00693	76.4	76.0	5.67	7.88	7.65	7.54	7.69	0.124
30	11.34940	76.2	75.8	5.10	6.39	6.02	5.93	6.11	0.174
31	11.69215	76.2	76.0	4.52	4.95	4.36	4.53	4.61	0.214
32	12.05490			3.92	3.42	2.61	3.05	3.03	0.289
33	12.39773	76.4	75.9	4.53	7.86	7.77	7.53	7.72	0.119
34	12.74051	76.6	76.2	5.10	10.34	10.14	10.09	10.19	0.095
35	13.08376	76.3	76.0	5.68	12.72	12.28	12.50	12.50	0.154
36	13.42624	76.2	76.0	6.25	15.24	14.78	15.14	15.05	0.169
37	13.76949	76.2	76.0	6.82	18.40	17.95	18.31	18.22	0.170
38	14.11250	76.2	75.9	7.39	22.64	22.23	22.83	22.57	0.217
39	14.47511			8.00	27.12	26.76	27.61	27.16	0.303
40	14.81803	76.4	76.0	7.37	15.93	15.67	15.82	15.81	0.094
41	15.16115	76.3	76.1	6.80	11.80	11.38	11.54	11.57	0.152
42	15.50364	76.5	76.0	6.23	9.20	8.95	8.96	9.04	0.101
43	15.84717	76.5	75.9	5.66	7.37	7.18	7.03	7.19	0.120
44	16.18947	76.5	76.0	5.08	5.81	5.65	5.45	5.64	0.125
45	16.53245	76.3	76.0	4.51	4.45	4.31	4.09	4.29	0.128
46	16.89455			3.90	3.03	2.89	2.66	2.86	0.132
47	17.23753	76.5	76.1	4.50	7.27	7.09	6.94	7.10	0.117
48	17.58038	76.3	76.1	5.08	9.74	9.88	9.46	9.69	0.153
49	17.92369	76.7	76.0	5.65	11.96	12.03	11.80	11.93	0.083
50	18.26606	76.4	76.2	6.22	14.51	14.18	14.35	14.35	0.115
51	18.60919	76.5	76.2	6.79	17.38	17.11	17.40	17.30	0.114
52	18.95166	76.3	76.0	7.37	21.54	21.21	21.56	21.44	0.137
53	19.31325			7.97	25.92	25.54	25.95	25.81	0.161
54	19.65618	76.5	76.1	7.32	15.24	15.12	15.05	15.14	0.067
55	19.99925	76.7	75.9	6.75	11.23	11.11	10.99	11.11	0.086
56	20.34244	76.5	76.1	6.18	8.77	8.69	8.50	8.65	0.098
57	20.68484	76.9	76.2	5.61	6.91	7.08	6.62	6.87	0.163
58	21.02751	76.3	76.0	5.04	5.39	5.54	5.07	5.33	0.172
59	21.37077	76.6	76.0	4.46	4.05	4.04	3.72	3.94	0.134

TABLE 30. 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 10 OF 15)

60	21.68537			3.93	2.82	2.66	2.48	2.66	0.121
61	21.69569	76.6	76.1	3.94	3.13	3.39	2.97	3.16	0.151
62	22.03863	77.1	76.2	4.51	6.83	6.80	6.76	6.79	0.026
63	22.38164	76.5	76.2	5.08	9.33	9.36	9.21	9.30	0.057
64	22.72419	76.9	76.0	5.66	11.56	11.57	11.55	11.56	0.007
65	23.06710	76.5	76.2	6.23	14.05	13.80	14.05	13.96	0.101
66	23.41033	76.6	76.2	6.80	16.94	16.84	17.05	16.94	0.074
67	23.75287	76.7	76.4	7.37	20.89	20.46	21.16	20.84	0.249
68	24.08557			7.92	24.73	23.97	25.15	24.62	0.421
69	24.09591	76.5	76.3	7.91	26.78	26.15	27.02	26.65	0.319
70	24.43905	76.6	76.3	7.35	15.11	14.80	15.14	15.02	0.132
71	24.78195	76.8	76.3	6.78	11.09	11.17	11.03	11.10	0.048
72	25.12460	76.7	76.3	6.21	8.60	8.18	8.50	8.43	0.155
73	25.46800	76.9	76.1	5.64	6.74	6.30	6.58	6.54	0.155
74	25.81034	76.7	76.4	5.07	5.25	5.29	5.04	5.19	0.094
75	26.15294	77.1	76.1	4.49	3.90	4.07	3.65	3.87	0.149
76	26.51526			3.89	2.46	2.79	2.19	2.48	0.214
77	26.85828	77.0	76.4	4.52	6.76	6.74	6.65	6.72	0.041
78	27.20153	76.7	76.4	5.09	9.18	9.22	9.05	9.15	0.064
79	27.54412	76.8	76.2	5.67	11.40	11.63	11.39	11.47	0.097
80	27.88735	76.8	76.5	6.24	13.80	14.13	13.86	13.93	0.124
81	28.22959	76.9	76.4	6.81	16.65	16.39	16.84	16.62	0.158
82	28.57255	76.7	76.3	7.38	20.63	20.56	20.89	20.69	0.125
83	28.93549			7.99	24.83	24.98	25.19	25.00	0.126
84	29.27824	76.8	76.2	7.39	15.15	14.97	15.11	15.07	0.067
85	29.62146	76.9	76.4	6.82	11.12	10.94	11.00	11.02	0.065
86	29.96399	77.1	76.4	6.25	8.58	8.54	8.43	8.52	0.055
87	30.30720	76.9	76.3	5.68	6.71	6.71	6.57	6.66	0.059
88	30.64994	77.0	76.4	5.11	5.20	4.87	5.01	5.03	0.118
89	30.99282	77.1	76.5	4.54	3.90	3.69	3.64	3.74	0.097
90	31.35502			3.93	2.52	2.45	2.19	2.39	0.122
91	31.69814	77.2	76.5	4.53	6.49	6.45	6.40	6.45	0.032
92	32.04118	77.1	76.3	5.10	8.84	8.63	8.83	8.77	0.083
93	32.38396	77.2	76.4	5.67	11.19	10.92	11.13	11.08	0.103
94	32.72699	77.3	76.6	6.25	13.57	13.25	13.55	13.46	0.127
95	33.06944	77.3	76.3	6.82	16.33	16.16	16.48	16.32	0.114
96	33.41208	77.1	76.4	7.39	20.21	19.89	20.48	20.19	0.209
97	33.77510			7.99	24.31	23.85	24.72	24.30	0.310
98	34.11826	77.1	76.5	7.38	14.80	14.43	14.80	14.68	0.151
99	34.46080	77.2	76.6	6.82	10.89	10.56	10.78	10.74	0.117
100	34.80374	77.1	76.5	6.25	8.40	8.32	8.27	8.33	0.049
101	35.14670	77.2	76.6	5.68	6.60	6.45	6.36	6.47	0.083
102	35.48994	77.2	76.5	5.10	5.08	4.86	4.82	4.92	0.098
103	35.83240	77.3	76.5	4.53	3.69	3.63	3.48	3.60	0.079
104	36.19523			3.92	2.23	2.32	2.05	2.20	0.100
105	36.53865	77.3	76.7	4.53	6.42	6.25	6.28	6.32	0.062
106	36.88115	77.6	76.6	5.10	8.78	8.78	8.69	8.75	0.039
107	37.22373	77.5	76.6	5.68	11.06	10.77	10.97	10.93	0.104
108	37.56681	77.1	76.6	6.25	13.44	12.89	13.40	13.24	0.214
109	37.90955	77.0	76.6	6.82	16.21	16.01	16.29	16.17	0.102
110	38.25241	77.0	76.6	7.39	20.06	19.64	20.24	19.98	0.217
111	38.61549			8.00	24.15	23.49	24.42	24.02	0.338
112	38.95827	77.0	76.8	7.39	14.67	14.24	14.63	14.51	0.170
113	39.30125	76.9	76.6	6.82	10.77	10.59	10.65	10.67	0.065
114	39.64460	76.8	76.6	6.25	8.28	8.28	8.16	8.24	0.049
115	39.98684	77.0	76.6	5.68	6.45	6.14	6.30	6.30	0.110
116	40.33004	76.6	76.4	5.11	4.96	4.97	4.78	4.90	0.076
117	40.67266	76.5	76.4	4.53	3.64	3.72	3.39	3.58	0.121
118	41.03509			3.93	2.25	2.40	1.93	2.19	0.172
119	41.37791	76.4	76.2	4.54	6.40	6.09	6.21	6.24	0.109
120	41.72090	76.6	76.3	5.12	8.73	8.51	8.65	8.63	0.078

TABLE 30. 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 11 OF 15)

121	42.06418	76.4	76.2	5.69	10.94	10.49	10.94	10.79	0.185
122	42.40658	76.1	76.1	6.26	13.41	13.11	13.38	13.30	0.114
123	42.74937	76.1	75.9	6.83	16.27	16.15	16.28	16.23	0.051
124	43.09250	75.9	75.8	7.41	20.07	19.54	20.30	19.97	0.276
125	43.45380			8.01	24.08	23.10	24.53	23.90	0.515
126	43.77670	75.8	75.9	7.36	14.38	13.83	14.31	14.17	0.211
127	44.13952	76.0	75.6	6.79	10.56	10.09	10.45	10.36	0.176
128	44.48292	76.0	75.6	6.22	8.14	7.88	7.99	8.00	0.093
129	44.82580	75.7	75.8	5.65	6.35	6.17	6.11	6.21	0.088
130	45.16792	75.8	75.6	5.08	4.85	4.86	4.56	4.76	0.118
131	45.51093	75.7	75.5	4.50	3.49	3.49	3.21	3.40	0.113
132	45.84334			3.94	2.18	2.16	1.91	2.08	0.108
133	45.85361	75.8	75.8	3.95	2.52	2.65	2.30	2.49	0.125
134	46.19653	75.7	75.6	4.52	6.23	6.08	6.03	6.11	0.072
135	46.53977	75.9	75.8	5.09	8.62	8.06	8.45	8.37	0.204
136	46.88214	75.8	75.7	5.67	10.90	10.54	10.74	10.73	0.129
137	47.22508	75.6	75.6	6.24	13.22	12.86	13.17	13.08	0.137
138	47.56827	75.7	75.7	6.81	16.05	15.60	16.04	15.90	0.180
139	47.91093	75.8	75.7	7.38	19.83	19.30	19.89	19.67	0.231
140	48.27385			7.99	23.83	23.21	23.98	23.67	0.288
141	48.61673	75.6	75.7	7.38	14.53	14.06	14.46	14.35	0.178
142	48.95995	75.7	75.8	6.81	10.65	10.36	10.42	10.50	0.103
143	49.30255	75.6	75.8	6.25	8.16	8.08	8.00	8.08	0.056
144	49.64519	75.9	75.8	5.67	6.34	6.02	6.10	6.15	0.117
145	49.98835	75.6	75.8	5.10	4.85	4.53	4.54	4.64	0.131
146	50.33095	75.6	75.8	4.53	3.47	3.23	3.21	3.30	0.101
147	50.69400			3.92	2.00	1.86	1.79	1.88	0.074
148	51.03687	76.1	75.8	4.52	6.16	5.63	5.99	5.93	0.186
149	51.37978	75.7	75.9	5.09	8.56	8.25	8.30	8.39	0.110
150	51.72260	75.8	75.6	5.67	10.83	10.29	10.60	10.57	0.190
151	52.06615	75.8	76.0	6.24	13.14	12.68	13.06	12.96	0.172
152	52.40829	75.8	76.0	6.81	15.89	15.42	15.88	15.73	0.188
153	52.75131	75.9	75.8	7.38	19.63	18.89	19.75	19.42	0.330
154	53.11390			7.99	23.59	22.55	23.84	23.33	0.482
155	53.45673	75.7	76.0	7.38	14.38	13.72	14.34	14.15	0.262
156	53.80002	75.7	75.9	6.81	10.49	9.81	10.39	10.23	0.257
157	54.14206	75.8	75.9	6.24	8.10	7.71	7.91	7.91	0.138
158	54.48586	75.9	76.0	5.67	6.23	5.81	6.00	6.02	0.150
159	54.82875	75.8	75.9	5.10	4.71	4.68	4.48	4.62	0.044
160	55.17092	75.9	75.9	4.53	3.36	3.22	3.16	3.24	0.073
161	55.51443			3.95	2.00	1.75	1.82	1.86	0.091
162	55.55532	76.2	75.9	3.97	2.69	2.50	2.61	2.60	0.067
163	56.24100	75.8	76.0	5.12	8.54	8.15	8.37	8.35	0.138
164	56.92621	75.9	76.0	6.27	13.08	12.75	12.92	12.92	0.115
165	57.61259	76.0	76.2	7.41	19.61	19.09	19.68	19.46	0.226
166	[illegible]	75.9	76.1	8.55	32.77	32.20	33.44	32.80	0.439
167	58.98386	76.2	76.2	9.69	39.32	38.32	39.92	39.19	0.573
168	59.66994	75.9	76.2	10.86	43.59	42.44	44.20	43.41	0.631
169	60.37566			12.06	47.97	46.68	48.60	47.75	0.691
170	60.71865	76.2	76.2	11.45	26.07	25.46	26.24	25.92	0.289
171	61.06170	76.2	76.1	10.87	19.68	19.12	19.61	19.47	0.214
172	61.40450	76.3	76.3	10.29	16.00	15.50	15.87	15.79	0.181
173	61.74770	76.5	76.2	9.71	13.38	12.92	13.22	13.17	0.165
174	62.09027	76.3	76.2	9.13	11.41	10.86	11.29	11.19	0.203
175	62.43270	76.3	76.2	8.56	9.81	9.32	9.69	9.61	0.180
176	62.77585			7.99	8.20	7.77	8.09	8.02	0.157
177	62.81698	76.4	76.2	8.00	9.20	8.45	9.04	8.90	0.280
178	63.16006	76.3	76.5	8.57	13.25	12.82	13.22	13.10	0.169
179	63.50262	76.5	76.3	9.13	16.32	16.15	16.27	16.25	0.063
180	63.84548	76.5	76.5	9.71	19.34	18.92	19.35	19.20	0.172

TABLE 30. 1/2-IN. BAR STRESS WHILE CYCLING (SHEET 12 OF 15)

181	64.18884	76.4	76.4	10.29	22.77	22.44	22.87	22.69	0.160
182	64.53186	76.5	76.5	10.88	27.26	26.48	27.32	27.02	0.332
183	64.87410	76.4	76.4	11.46	33.38	32.41	33.60	33.13	0.446
184	65.23684			12.07	39.86	38.70	40.25	39.61	0.571
185	65.58008	76.6	76.3	11.47	23.93	22.98	24.00	23.64	0.400
186	65.92320	76.5	76.5	10.89	18.12	17.48	18.07	17.89	0.252
187	66.26555	76.5	76.4	10.30	14.66	14.20	14.57	14.48	0.175
188	66.60820	76.5	76.6	9.73	12.36	11.87	12.20	12.14	0.175
189	66.95145	76.5	76.5	9.15	10.58	9.62	10.22	10.14	0.342
190	67.29457	76.6	76.4	8.58	9.06	8.75	8.68	8.83	0.143
191	67.63680	76.8	76.5	8.00	7.72	7.37	7.32	7.47	0.152
192	67.67079			7.94	7.58	7.24	7.19	7.34	0.153
193	67.68110	76.6	76.4	7.96	7.83	7.28	7.57	7.56	0.192
194	68.02414	76.7	76.5	8.53	12.08	11.68	11.81	11.85	0.144
195	68.36718	76.9	76.4	9.10	14.92	14.41	14.70	14.68	0.181
196	68.70974	76.6	76.4	9.67	17.75	17.26	17.55	17.52	0.175
197	69.05241	77.0	76.6	10.25	20.91	20.38	20.73	20.67	0.192
198	69.39534	76.6	76.6	10.84	24.76	24.17	24.66	24.53	0.223
199	69.73815	76.7	76.6	11.42	30.05	29.29	30.14	29.83	0.331
200	70.08162			12.00	35.35	34.42	35.64	35.14	0.451
201	70.12405	76.6	76.6	12.02	37.26	35.82	37.09	36.73	0.558
202	70.46712	76.7	76.6	11.44	22.63	21.78	22.56	22.33	0.332
203	70.81010	76.7	76.6	10.86	17.30	16.69	17.06	17.02	0.218
204	71.15259	76.9	76.5	10.28	14.08	13.56	13.78	13.80	0.183
205	71.49607	77.0	76.5	9.70	11.74	11.26	11.48	11.49	0.170
206	71.83895	76.9	76.5	9.13	9.96	9.69	9.66	9.77	0.116
207	72.18119	77.0	76.5	8.55	8.47	8.22	8.16	8.28	0.115
208	72.52425	77.1	76.8	7.97	7.25	6.86	6.80	6.97	0.174
209	72.57239			7.89	7.08	6.66	6.61	6.79	0.182
210	72.58267	77.3	76.5	7.91	7.36	6.83	7.02	7.07	0.193
211	72.92575	77.3	76.8	8.48	11.47	10.73	11.16	11.12	0.262
212	73.26850	76.9	76.8	9.05	14.15	13.84	13.94	13.98	0.114
213	73.61140	77.2	76.7	9.62	16.83	16.37	16.65	16.62	0.165
214	73.95402	77.0	76.8	10.21	19.84	18.94	19.68	19.49	0.342
215	74.29696	76.9	76.8	10.78	23.36	22.36	23.33	23.02	0.402
216	74.64032	77.0	76.7	11.36	28.22	27.78	28.34	28.11	0.209
217	74.98262	77.0	76.9	11.94	35.95	34.58	36.25	35.59	0.629
218	75.03589			12.03	37.15	35.64	37.48	36.76	0.694
219	75.04620	77.0	76.8	12.03	36.69	35.04	36.62	36.12	0.662
220	75.38914	77.2	76.9	11.45	22.15	21.48	22.08	21.91	0.260
221	75.73205	76.9	76.8	10.87	16.90	16.35	16.72	16.66	0.197
222	76.07490	77.2	76.9	10.29	13.72	13.42	14.49	14.54	0.113
223	76.41758	77.0	76.8	9.71	11.45	10.87	11.19	11.17	0.205
224	76.76115	77.0	76.8	9.13	9.70	9.24	9.37	9.44	0.168
225	77.10362	77.0	76.9	8.56	8.24	7.88	7.91	8.01	0.142
226	77.44610			7.99	6.78	6.53	6.44	6.58	0.127
227	77.48795	76.9	76.8	7.98	7.48	7.30	7.13	7.30	0.124
228	77.83076	76.8	76.8	8.55	11.35	10.66	11.05	11.02	0.245
229	78.17422	77.1	76.6	9.12	14.04	13.51	13.80	13.79	0.190
230	78.51643	76.7	76.8	9.70	16.75	16.23	16.50	16.49	0.183
231	78.85979	76.7	76.8	10.28	19.71	19.15	19.55	19.47	0.202
232	79.20236	76.5	76.8	10.86	23.31	23.03	23.28	23.21	0.107
233	79.54500	76.5	76.8	11.44	28.27	27.63	28.44	28.11	0.300
234	79.88815			12.02	33.24	32.24	33.60	33.03	0.498
235	79.92850	76.5	76.9	12.00	34.27	33.05	34.26	33.86	0.498
236	80.27202	76.3	76.8	11.43	21.50	20.75	21.30	21.18	0.274
237	80.61480	76.3	76.5	10.85	16.49	15.89	16.18	16.19	0.210
238	80.95704	76.4	76.4	10.27	13.42	12.93	13.07	13.14	0.176
239	81.29985	76.4	76.5	9.69	11.21	10.67	10.83	10.90	0.198
240	81.64339	76.1	76.5	9.11	9.39	8.81	9.03	9.08	0.207
241	81.98627	76.0	76.3	8.53	7.91	7.39	7.57	7.62	0.185

TABLE 30. 1/2-IN. BAR STRESS WHILE CYCLING (SHEET 13 OF 15)

242	82.34858			7.92	6.34	5.89	6.02	6.09	0.164
243	82.69210	75.9	76.3	8.57	11.12	10.77	10.83	10.91	0.135
244	83.03434	75.9	76.4	9.14	13.86	13.25	13.58	13.56	0.218
245	83.37713	75.9	76.2	9.72	16.51	15.80	16.28	16.19	0.257
246	83.72000	75.7	76.0	10.30	19.49	19.02	19.30	19.27	0.166
247	84.06339	75.6	76.3	10.88	23.13	22.21	23.01	22.78	0.353
248	84.40590	75.6	76.2	11.46	28.02	26.90	28.20	27.71	0.501
249	84.76873			12.07	33.21	31.87	33.71	32.93	0.674
250	85.11190	75.6	76.2	11.47	21.63	20.51	21.42	21.19	0.421
251	85.45476	75.9	76.1	10.88	16.52	15.56	16.20	16.09	0.344
252	85.79725	75.7	76.2	10.30	13.29	12.59	13.02	12.97	0.249
253	86.14009	75.8	76.2	9.73	11.11	10.23	10.78	10.71	0.316
254	86.48366	75.5	76.1	9.15	9.27	8.79	8.95	9.00	0.172
255	86.82636	75.6	76.2	8.57	7.85	7.37	7.47	7.56	0.177
256	87.16879			8.00	6.42	5.95	6.00	6.12	0.185
257	87.21110	75.6	76.4	8.01	7.22	6.80	6.90	6.97	0.156
258	87.55424	75.7	76.2	8.58	10.98	10.26	10.63	10.62	0.254
259	87.89750	75.7	76.4	9.16	13.67	12.92	13.41	13.33	0.269
260	88.24031	75.8	76.2	9.73	16.34	15.70	16.09	16.04	0.228
261	88.58294	75.7	76.3	10.32	19.23	18.26	19.09	18.86	0.372
262	88.92570	75.7	76.3	10.89	22.83	21.85	22.76	22.48	0.386
263	89.26830	75.8	76.1	11.47	27.85	26.47	27.82	27.38	0.556
264	89.63106			12.08	33.16	31.36	33.17	32.56	0.736
265	89.97389	75.7	76.4	11.46	21.26	20.21	21.07	20.85	0.393
266	90.31715	75.8	76.3	10.88	16.21	15.41	15.96	15.86	0.289
267	90.65963	75.9	76.3	10.30	13.21	11.76	12.83	12.60	0.530
268	91.00313	75.9	76.5	9.72	10.91	10.01	10.59	10.50	0.323
269	91.34572	75.9	76.3	9.14	9.26	8.52	8.79	8.85	0.264
270	91.68815	75.9	76.4	8.57	7.70	7.06	7.34	7.37	0.227
271	92.03160			7.99	6.14	5.60	5.89	5.88	0.191
272	92.07254	75.7	76.5	7.98	6.84	6.00	6.47	6.44	0.297
273	92.41599	76.1	76.4	8.55	10.69	9.80	10.38	10.29	0.319
274	92.75875	75.9	76.4	9.12	13.39	12.41	13.06	12.95	0.354
275	93.10115	76.1	76.3	9.69	15.91	14.95	15.72	15.52	0.359
276	93.44418	75.8	76.4	10.28	18.86	17.73	18.60	18.39	0.417
277	93.78690	75.8	76.6	10.85	22.28	21.14	22.15	21.86	0.441
278	94.13026	75.9	76.4	11.44	27.01	25.85	26.99	26.62	0.468
279	94.47266			12.02	31.72	30.55	31.81	31.36	0.498
280	94.51315	75.9	76.4	12.00	32.92	31.31	32.72	32.32	0.621
281	94.85646	76.0	76.5	11.43	20.72	19.74	20.48	20.31	0.358
282	95.19885	76.0	76.4	10.85	15.87	14.96	15.60	15.48	0.329
283	95.54230	76.0	76.3	10.26	12.84	12.28	12.55	12.56	0.198
284	95.88524	76.0	76.2	9.68	10.71	9.76	10.36	10.28	0.341
285	96.22789	76.1	76.5	9.11	8.97	8.08	8.61	8.55	0.320
286	96.57071	76.0	76.5	8.53	7.49	6.64	7.15	7.10	0.303
287	96.93255			7.92	5.93	5.13	5.61	5.56	0.285
288	97.27567	76.4	76.5	8.55	10.51	9.95	10.24	10.24	0.198
289	97.61854	76.2	76.5	9.12	13.16	12.10	12.90	12.72	0.392
290	97.96165	76.1	76.5	9.69	15.78	15.07	15.53	15.46	0.253
291	98.30405	76.0	76.4	10.27	18.55	17.78	18.37	18.23	0.285
292	98.64725	76.1	76.6	10.85	21.97	21.17	21.85	21.66	0.303
293	98.98996	76.1	76.6	11.43	26.67	25.84	26.65	26.39	0.333
294	99.35204			12.05	31.64	30.78	31.72	31.38	0.370
295	99.69545	76.4	76.4	11.45	20.70	19.63	20.51	20.28	0.403
296	100.03771	76.2	76.4	10.87	15.88	15.11	15.57	15.52	0.272
297	100.38059	76.4	76.4	10.28	12.85	11.69	12.54	12.36	0.424
298	100.72345	76.3	76.7	9.70	10.64	10.33	10.32	10.43	0.130
299	101.06668	76.3	76.4	9.13	8.97	8.36	8.58	8.64	0.220
300	101.40969	76.3	76.7	8.55	7.45	7.21	7.10	7.25	0.126
301	101.75201			7.97	5.92	6.05	5.62	5.86	0.157
302	101.79253	76.4	76.4	7.95	6.50	6.10	6.19	6.26	0.150

TABLE 30. 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 14 OF 15)

303	102.13579	76.4	76.7	8.53	10.33	9.74	10.07	10.05	0.210
304	102.47835	76.6	76.4	9.10	13.03	12.66	12.67	12.78	0.149
305	102.82107	76.3	76.7	9.67	15.55	15.20	15.27	15.34	0.131
306	103.16400	76.4	76.9	10.26	18.30	17.56	18.13	18.00	0.273
307	103.50675	76.4	76.7	10.83	21.67	20.93	21.49	21.36	0.275
308	103.84985	76.5	76.7	11.42	26.15	25.31	26.20	25.89	0.352
309	104.19245			12.00	30.63	29.70	30.90	30.41	0.446
310	104.23299	76.3	76.8	12.04	33.78	32.50	33.82	33.37	0.528
311	104.57618	76.6	76.7	11.47	20.72	19.98	20.49	20.39	0.267
312	104.91885	76.5	76.6	10.89	15.81	15.28	15.53	15.54	0.186
313	105.26146	76.6	76.6	10.31	12.78	12.26	12.53	12.52	0.184
314	105.60444	76.6	76.9	9.73	10.64	10.05	10.30	10.33	0.211
315	105.94774	76.7	76.8	9.15	8.91	8.55	8.55	8.67	0.147
316	106.29054	76.7	76.9	8.58	7.42	6.82	7.05	7.10	0.214
317	106.63322			8.00	5.93	5.09	5.56	5.52	0.298
318	106.67593	76.8	76.8	7.97	6.42	5.56	6.08	6.02	0.307
319	107.01948	76.9	76.8	8.54	10.22	9.62	9.98	9.94	0.214
320	107.36178	76.6	76.9	9.12	12.87	12.08	12.58	12.51	0.283
321	107.70476	76.7	76.9	9.69	15.46	14.99	15.18	15.21	0.170
322	108.04778	76.8	77.0	10.28	18.21	17.47	17.98	17.89	0.265
323	108.39058	76.8	76.9	10.85	21.56	20.62	21.40	21.19	0.354
324	108.73310	76.8	77.0	11.43	26.03	25.01	26.03	25.69	0.419
325	109.07600			12.02	30.52	29.39	30.67	30.19	0.492
326	109.11885	76.9	76.9	11.99	31.31	29.68	31.14	30.71	0.633
327	109.80496	77.0	77.0	10.83	15.40	14.44	15.10	14.98	0.347
328	110.49023	77.1	77.0	9.67	10.39	9.70	10.03	10.04	0.245
329	111.17603	77.1	77.2	8.52	7.27	6.92	6.84	7.01	0.161
330	111.86238	77.1	77.0	7.38	4.82	4.48	4.43	4.58	0.149
331	112.54743	77.2	77.1	6.24	3.04	2.70	2.61	2.78	0.162
332	113.23370	77.3	77.1	5.09	1.48	0.81	1.04	1.11	0.242
333	113.90282			3.96	0.00	0.00	0.00	0.00	0.000
334	113.91317	77.5	77.5	3.98	0.00	0.00	0.00	0.00	0.000
335	114.25626	77.6	77.4	4.55	3.40	2.92	3.01	3.11	0.180
336	114.59879	77.4	77.4	5.12	5.23	4.68	4.97	4.96	0.194
337	114.94216	77.7	77.2	5.69	6.87	6.55	6.59	6.67	0.124
338	115.28495	77.3	77.2	6.27	8.40	7.88	8.10	8.13	0.185
339	115.62779	77.4	77.2	6.83	9.92	9.11	9.61	9.55	0.287
340	115.97046	77.2	77.2	7.41	11.39	10.42	11.10	10.97	0.350
341	116.30202			7.96	12.81	11.69	12.53	12.34	0.413
342	116.31235	77.2	77.3	7.95	12.41	11.83	12.19	12.14	0.207
343	116.65557	77.0	77.2	7.38	8.32	7.52	8.04	7.96	0.287
344	116.99854	77.1	77.3	6.82	6.42	6.05	6.05	6.17	0.151
345	117.34157	77.2	77.2	6.25	4.89	4.58	4.54	4.67	0.135
346	117.68433	76.9	77.1	5.67	3.60	2.92	3.25	3.26	0.241
347	118.02685	77.1	77.0	5.10	2.56	2.20	2.08	2.28	0.178
348	118.36969	77.2	77.1	4.53	1.51	1.02	1.03	1.19	0.196
349	118.70330			3.97	0.48	-0.13	0.02	0.12	0.224
350	118.71368	77.0	77.1	3.98	0.74	0.00	0.37	0.37	0.263
351	119.05659	76.8	77.0	4.54	3.89	3.20	3.59	3.56	0.246
352	119.40001	76.8	77.1	5.11	5.84	5.29	5.52	5.55	0.196
353	119.74239	76.5	76.9	5.69	7.47	6.91	7.19	7.19	0.198
354	120.08500	76.5	76.6	6.26	9.02	8.70	8.74	8.82	0.122
355	120.42846	76.5	76.6	6.83	10.56	9.92	10.29	10.26	0.229
356	120.77066	76.3	76.7	7.40	12.12	11.19	11.84	11.72	0.337
357	121.13370			8.01	13.77	12.54	13.48	13.27	0.455
358	121.47650	76.3	76.7	7.36	8.78	7.93	8.49	8.40	0.306
359	121.81948	76.0	76.6	6.79	6.80	5.73	6.42	6.32	0.385
360	122.16266	76.0	76.5	6.22	5.27	4.39	4.84	4.83	0.309
361	122.50503	75.9	76.4	5.65	3.90	3.43	3.54	3.62	0.172
362	122.84802	75.9	76.5	5.07	2.72	1.97	2.32	2.34	0.265
363	123.19144	75.9	76.4	4.50	1.66	1.33	1.22	1.40	0.163
364	123.51307			3.96	0.67	0.73	0.19	0.53	0.209
365	123.52342	76.0	76.6	3.97	0.86	0.28	0.50	0.55	0.209
366	123.86648	75.7	76.5	4.54	4.15	3.44	3.76	3.78	0.252
367	124.20911	75.9	76.4	5.11	6.07	5.43	5.72	5.74	0.229
368	124.55249	75.7	76.5	5.69	7.76	6.78	7.42	7.32	0.350

TABLE 30. 1/2-IN. BAR STRESS WHILE CYCLING
(SHEET 15 OF 15)

369	124.89486	75.8	76.5	6.26	9.29	8.53	9.01	8.95	0.271
370	125.23814	75.9	76.5	6.83	10.81	10.12	10.57	10.50	0.346
371	125.58055	75.5	76.3	7.40	12.41	11.97	12.16	12.18	0.157
372	125.94280			8.01	14.11	13.93	13.85	13.96	0.096
373	126.28570	75.6	76.4	7.37	9.20	8.41	8.79	8.80	0.281
374	126.62850	75.6	76.5	6.80	7.04	6.36	6.65	6.60	0.243
375	126.97140	75.7	76.4	6.23	5.41	4.71	5.05	5.06	0.249
376	127.31440	75.9	76.2	5.66	4.11	3.68	3.67	3.82	0.178
377	127.65706	75.7	76.5	5.08	2.92	2.26	2.48	2.55	0.235
378	128.00000	75.7	76.5	4.51	1.26	0.95	1.36	1.36	0.287
379	128.36300			3.90	0.54	-0.45	0.17	0.09	0.351
380	128.70626	75.7	76.5	4.54	4.26	3.57	3.88	3.91	0.245
381	129.04861	75.6	76.4	5.11	6.20	5.35	5.86	5.80	0.303
382	129.39209	75.6	76.5	5.69	7.85	7.18	7.54	7.52	0.238
383	129.73432	75.7	76.5	6.26	9.44	8.25	9.16	8.95	0.440
384	130.07760	75.7	76.5	6.83	10.96	10.04	10.75	10.59	0.342
385	130.42069	75.8	76.2	7.40	12.59	11.61	12.34	12.18	0.363
386	130.75319			7.95	14.18	13.12	13.87	13.72	0.384
387	130.76350	75.5	76.4	7.94	13.90	12.60	13.60	13.36	0.481
388	131.10642	75.7	76.4	7.38	9.32	8.40	9.03	8.92	0.335
389	131.44955	75.8	76.5	6.81	7.18	6.15	6.84	6.72	0.370
390	131.79233	76.1	76.3	6.24	5.53	4.91	5.21	5.22	0.222
391	132.13514	75.9	76.2	5.67	4.15	3.53	3.79	3.82	0.220
392	132.47798	75.8	76.4	5.09	2.94	2.37	2.63	2.71	0.144
393	132.82093	75.9	76.5	4.52	1.84	1.26	1.45	1.52	0.287
394	133.15012			3.97	0.77	0.01	0.33	0.37	0.321
395	133.16050	76.0	76.6	3.98	1.03	0.37	0.65	0.68	0.233
396	133.50340	76.2	76.6	4.54	4.17	3.71	3.92	3.94	0.162
397	133.84667	75.8	76.4	5.12	6.16	5.41	5.91	5.83	0.267
398	134.18950	76.0	76.7	5.69	7.88	7.24	7.63	7.58	0.228
399	134.53217	76.0	76.5	6.26	9.36	8.89	9.25	9.17	0.172
400	134.87468	75.8	76.4	6.83	11.12	10.48	10.81	10.80	0.226
401	135.21799	75.9	76.6	7.41	12.72	11.83	12.44	12.33	0.323
402	135.54712			7.96	14.26	13.12	13.99	13.79	0.422
403	135.55744	75.8	76.6	7.94	14.03	13.01	13.71	13.59	0.369
404	135.90052	76.1	76.5	7.38	9.40	8.73	9.11	9.08	0.237
405	136.24318	75.9	76.5	6.81	7.23	6.86	6.91	7.00	0.145
406	136.58615	76.1	76.7	6.24	5.55	5.05	5.23	5.28	0.179
407	136.92950	76.4	76.3	5.67	4.16	3.64	3.88	3.90	0.184
408	137.27200	76.2	76.5	5.09	2.97	2.59	2.61	2.72	0.151
409	137.61480	76.2	76.8	4.52	1.85	1.47	1.49	1.60	0.152
410	137.95777			3.95	0.73	0.36	0.37	0.49	0.153
411	137.99948	76.2	76.7	3.92	0.99	0.56	0.70	0.75	0.156
412	138.34275	76.1	76.6	4.49	4.12	3.78	3.88	3.93	0.122
413	138.68513	76.0	76.6	5.06	6.07	5.07	5.81	5.65	0.368
414	139.02861	76.1	76.6	5.64	7.81	6.67	7.52	7.33	0.419
415	139.37078	76.1	76.7	6.21	9.43	7.89	9.14	8.82	0.576
416	139.71382	76.2	76.6	6.78	10.89	9.76	10.72	10.46	0.430
417	140.05702	76.0	76.7	7.35	12.52	11.25	12.34	12.04	0.485
418	140.39932	76.2	76.6	7.92	14.26	12.84	14.10	13.74	0.549

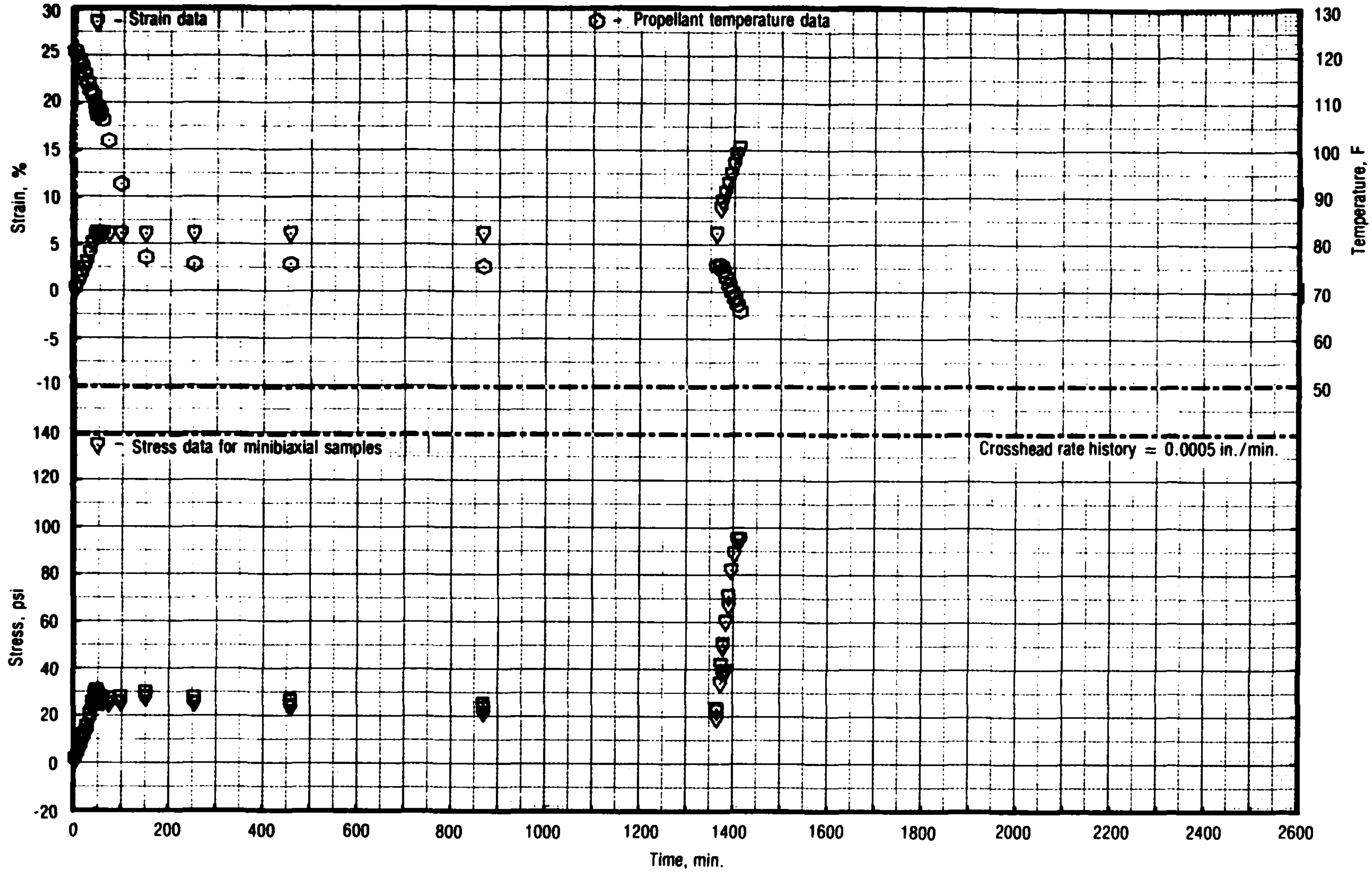


Figure 60. Test No. 21 - Stress While Complex Straining and Cooling for UTP-3001-750/7768

28827

TABLE 31. MINIBIAXIAL STRESS WHILE COMPLEX STRAINING AND COOLING
(SHEET 1 OF 2)

PROPELLANT: UTP 3001 750/7768
REQUESTOR: Carlton,Francis
WOR: 2742-400-0000

DATE: 1/5/82
OPERATOR: JWD

DEFINITIONS:
Time = Time From Start of Test (min)
σ = Stress (psi)
ε = Strain (%)
T(air) = Test Air Temperature (F)
T(prop) = Test Propellant Temperature (F)

RELATIONSHIPS:
σ = Force/Area
ε = Sample Extension/Length

NOMINAL VALUES:
Test Temp = 120,70,hold,40F F
Gage Length = 1.25 in
Nom. Strain = 0,6,10 %
XHD Rate = .0005 in/min

CALIBRATION DATA:

			SAMPLE	
Pretest:	Cal Wt = 10.0 lbs	1	2	3
Load Cal	(lbs/volts)	29.713	29.633	29.910
Offset	(volts)	0.051	0.116	0.105
Pot Cal	(in/volts) =	-0.389		
Temp	(F) =	119.8		
Post Test:	Cal Wt = 10.0 lbs			
Load Cal	(lbs/volts)	29.756	29.505	29.874
Offset	(volts)	0.199	0.099	0.135
Pot Cal	(in/volts) =	-0.392		
Temp	(F) =	65.4		

AREAS (sq in): 1.480 1.453 1.480

STRESS DATA (psi):

					SAMPLE				
SET	Time	T(prop)	T(air)	Strain	1	2	3	Avg	St Dev
1	-2.87174	121.1	121.3	0.00	0.06	0.01	0.05	0.04	0.018
2	3.37825	121.3	123.2	0.37	0.75	1.52	1.63	1.30	0.338
3	9.62879	119.6	121.4	1.00	3.36	4.45	4.59	4.14	0.476
4	15.87840	118.1	117.9	1.71	6.38	7.89	7.99	7.42	0.637
5	22.12876	116.4	115.2	2.54	10.11	11.84	11.89	11.28	0.718
6	28.37846	114.6	114.0	3.16	13.23	15.21	15.23	14.56	0.809
7	34.62882	112.8	111.2	4.18	18.25	20.53	20.42	19.73	0.910
8	40.87880	111.8	112.1	5.20	23.17	25.53	25.44	24.71	0.945
9	47.12866	109.7	107.5	5.99	26.41	28.99	28.81	28.07	1.019
10	49.44041	109.0	108.3	6.26	28.03	30.67	30.32	29.67	1.014
11	49.48019	109.1	110.0	6.27	28.05	30.61	30.33	29.66	0.993
12	49.54240			6.27	28.08	30.52	30.34	29.64	0.963
13	49.75356	108.7	108.3	6.27	27.74	30.24	30.00	29.33	0.973
14	49.95449	108.6	108.3	6.26	27.56	29.99	29.79	29.11	0.954
15	50.35535	109.0	105.3	6.26	27.35	29.75	29.52	28.87	0.937
16	51.15616	108.0	109.7	6.26	27.07	29.25	29.25	28.52	0.889
17	52.75655	107.4	107.5	6.26	26.52	28.12	28.63	27.76	0.777
18	55.95708	108.0	108.7	6.26	25.99	26.56	27.96	26.84	0.717
19	62.35736	106.6	106.3	6.25	25.58	25.53	27.49	26.20	0.791
20	75.15802	102.1	99.3	6.24	25.34	25.09	27.27	25.90	0.843
21	100.75874	92.9	90.9	6.24	25.80	25.56	27.87	26.41	0.897
22	153.49094	77.3	73.8	6.21	27.57	27.94	29.99	28.50	0.921
23	255.89124	75.9	69.3	6.23	25.32	25.49	27.59	26.13	0.895

TABLE 31. MINIBIAXIAL STRESS WHILE COMPLEX STRAINING AND COOLING (SHEET 2 OF 2)

24	460.69174	75.9	75.1	6.23	24.29	23.67	26.34	24.77	0.989
25	870.29243	75.4	75.1	6.23	23.36	21.39	24.90	23.22	1.243
26	1365.87154	75.5	77.4	6.23	22.37	19.17	22.96	21.50	1.442
27	1366.03595			6.23	22.37	19.17	22.96	21.50	1.442
28	1366.04624	75.6	77.6	6.23	22.34	19.06	22.85	21.42	1.454
29	1374.70000	75.6	77.5	8.90	41.50	34.00	42.00	39.17	3.169
30	1378.54646	74.6	73.6	9.65	49.65	38.56	50.62	46.28	4.738
31	1384.79651	73.1	73.1	10.58	60.16	39.00	60.28	53.14	8.662
32	1391.04661	71.5	72.9	11.52	70.88		67.04	68.96	2.713
33	1397.29641	70.1	68.9	12.56	81.90			81.90	0.000
34	1403.54688	68.7	67.9	13.59	89.00			89.00	0.000
35	1409.79659	67.3	68.2	14.62	94.86			94.86	0.000
36	1416.04644	65.9	66.6	15.33	94.92			94.92	0.000

TABLE 32. STRESS-STRAIN COMPARISON FOR UTP-3001 TESTS PHASE III

T8613

Test No.	Temperature, F	Rate, in./min.	Strain, %	Stress, psi	Stress Test No. 15	Difference, %	Box No.	Days After Machining	Remarks
14	41	2	6.85	290			2	3	Average
	41	2	9.65	352			2	3	Sample No. 3
	41	0.2	10.26	239			2	3	
	41	0.02	5.29	123			2	3	Average
	41	0.02	10.10	209			2	3	No. 3
	70	2	10.14	203			1	5	
	71	0.2	9.84	147			1	5	
	71	0.02	9.86	115			1	5	
	116	2	10.38	97.0			2	2	
	118	0.2	5.03	28.0			2	2	Average
	118	0.2	10.09	64.3			2	2	No.1
14	118	0.02	10.17	48.6			2	2	No.3
15 (1)	99.2	0.000027	1.50	10.4			3	4	Straining-cooling
16	40	0.2	3.13	107	95	12.6	3	10	
16	73	0.2	3.22	50.8	53	-4.2	3	4	
16	117	0.2	3.30	20.5	21	-2.4	3	5	
17 (2)	74	0.2	5.08	21.3	≈23.2	-8.2	-	11	No. 1 shear
17	74	0.2	5.87	23.6	≈26.5	-14.2	-	11	No. 2 shear
17	74	0.2	6.52	25.0	≈29.2	-14.4	-	11	No. 3 shear
18 (1)	95.2	0.0002	2.53	9.57			1	7	Straining-cooling
18	97.6	0.0004	2.29	10.4			1	3	" "
18	190.4	0.002	1.95	7.97			1	5	" "
19	74	1	2.26	37.0	~42	-11.9	4	18	No. 3
21 (1)	118.1	0.0005	1.71	7.42			4	5	Straining-cooling

Notes: (1) Insufficient data to extrapolate to an equivalent temperature for stress adjustment.
(2) Comparison of shear to biaxial data is only approximate.

TABLE 33. STRESS-STRAIN COMPARISON FOR UTP-19,360B TESTS PHASE III

T8612

Test No.	Temperature, F	Rate, in./min.	Strain, %	Stress, psi	Stress Test #15	Difference, %	Box No.	Days After Machining	Remarks
14	41	2	10.01	112			2	8	Average
	41	2	10.01	111			2	8	Sample #2
	41	0.2	10.22	80.6			2	8	
	41	0.02	10.15	63.0			2	8	
	71	2	8.63	81.4			1	2	
	70	0.2	10.20	65.6			1	3	Average #2 and 3
	71	0.02	10.03	50.4			1	7	
	120	2	10.13	63.9			2	6	
	119	0.2	10.24	50.4			2	7	Average
	119	0.2	9.87	49.4			2	7	#1
	118	0.02	10.02	40.0			2	7	Average
14	118	0.02	10.14	40.3			2	7	#2
15 (1)	99.5	0.00004	2.13	5.09	~ 4.50	13.1	3	2	Straining-cooling
16	40	0.2	3.50	44.0	40.0	10.0	3	12	
16	70	0.2	3.18	30.0	28.8	4.2	3	6	
16	117	0.2	3.09	19.6	16.7	17.4	3	7	
17	70	0.2	5.33	13.8	≈13.0	6.2	-	13	#1 Shear
17	70	0.2	5.73	14.5	≈13.7	5.8	-	13	#2 Shear
17	70	0.2	5.79	14.6	≈13.8	5.8	-	13	#3 Shear
18 (1)	95.2	0.0002	2.53	6.39	~ 6.20	3.1	1	9	Straining-cooling
18	97.6	0.0004	2.29	6.91	~ 6.10	13.3	1	4	" "
18	98.2	0.002	2.59	8.07	~ 8.60	-6.2	1	7	" "
19	70	1	1.91	29.0	23.4	23.9	4	7	Average #2 and 3
21 (1)	118.3	0.0005	1.83	6.34	~ 4.70	34.9	4	4	Straining-cooling

Notes: (1) Straining-cooling tests were compared as small strain and accompanying temperature to avoid the strain-thermal shift complication.

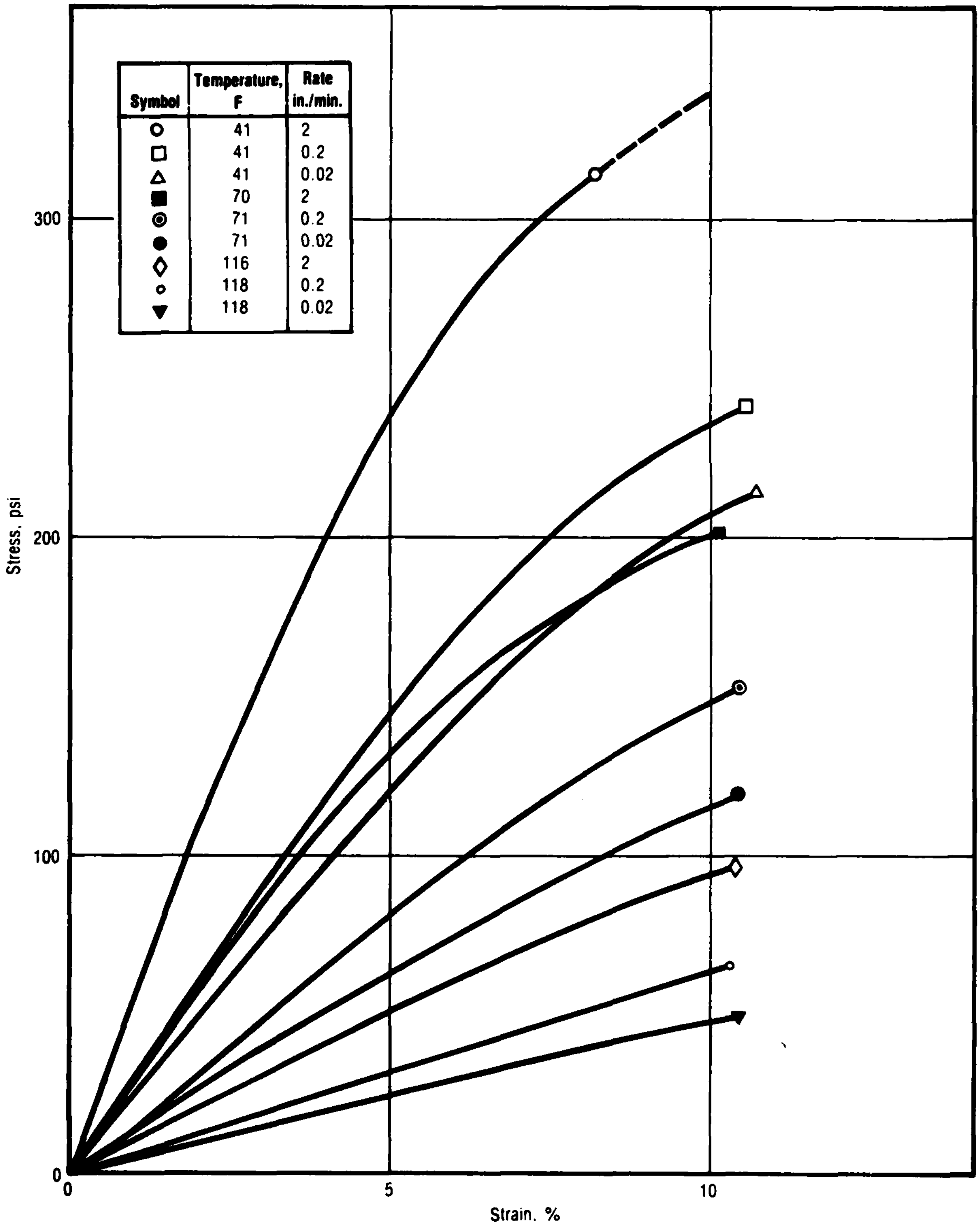


Figure 61. Biaxial Constant Rate Data for UTP-3001

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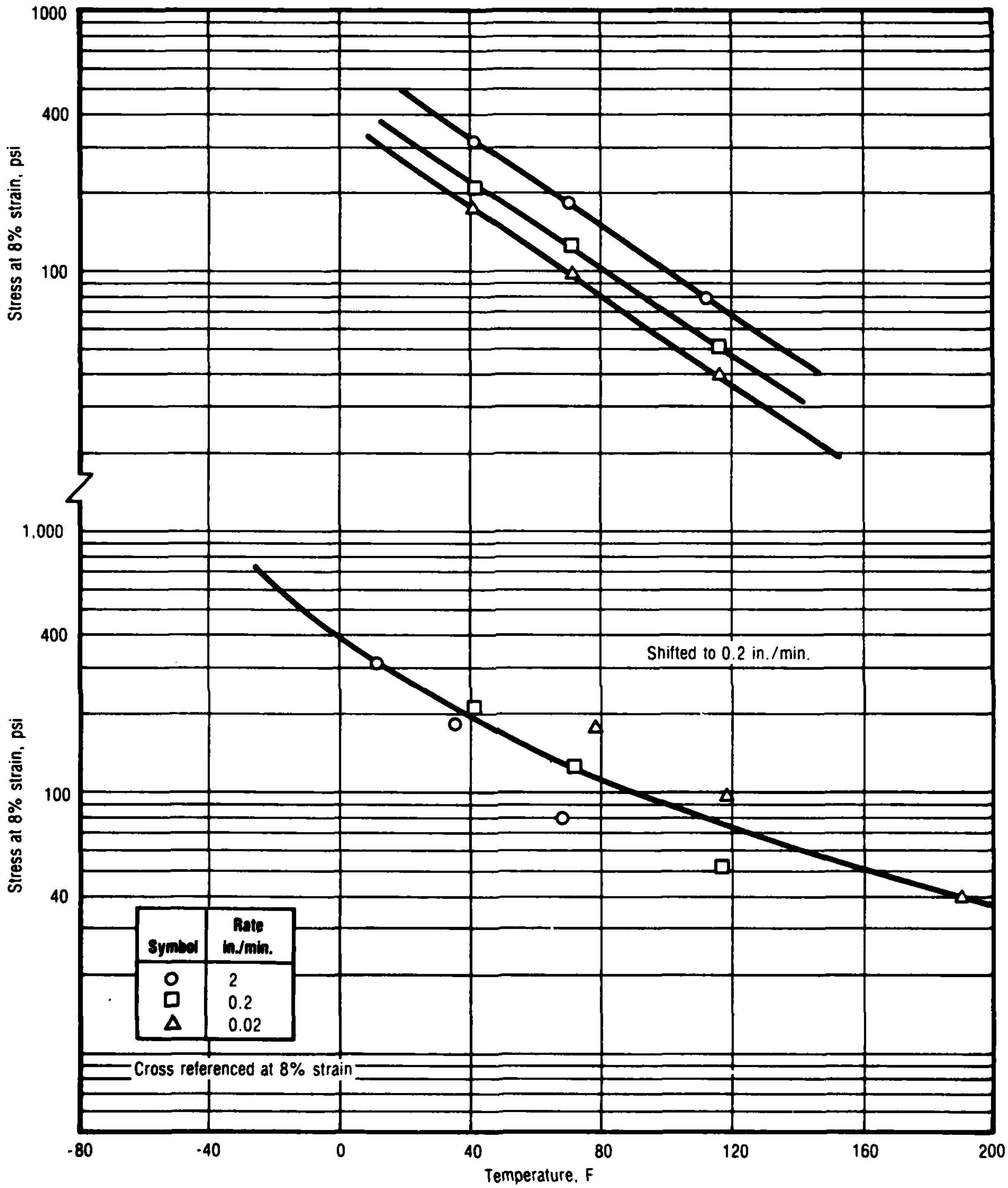

Figure 62. Test No. 14 - Biaxial Constant Rate Data for UTP-3001

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The UTP-19,360B biaxial constant rate data plotted in Figure 63 were used to obtain the stress comparison data (Table 33) at different strain levels. The stress-temperature plot in Figure 64 gave a good temperature extrapolation which was used to obtain comparison stress values for the slower rate straining-cooling tests. The stress values selected for comparison were early in the test at an elevated temperature and small strain. This was chosen to specifically avoid the complication of evaluating the combined thermal-mechanical interaction shift factor (A_F). While one of the straining-cooling tests showed a difference of 35%, the absolute delta stress was small.

Uniaxial, Biaxial and Shear Comparison

Comparisons of the different samples were made in order to show that the propellant, used in each of the tests, was of the same family. This was done at ambient temperature for selected rates and was limited to strain rates that were close to each other. This minimized the time-temperature equivalence shifts to small changes for neglectable data input errors. The adjustments made for strain levels are given in Table 34.

The comparisons between uniaxial and biaxial in the table are close to the theoretical ratio of 75 to 80%. The shear to uniaxial ratios of 0.28 and 0.39 bracket the nominal theoretical value of 1/3. For the comparisons made in Table 34, the UTP-3001 and UTP-19,360B propellants have to be considered part of the same family. Any minor differences can be attributed to a between carton effect.

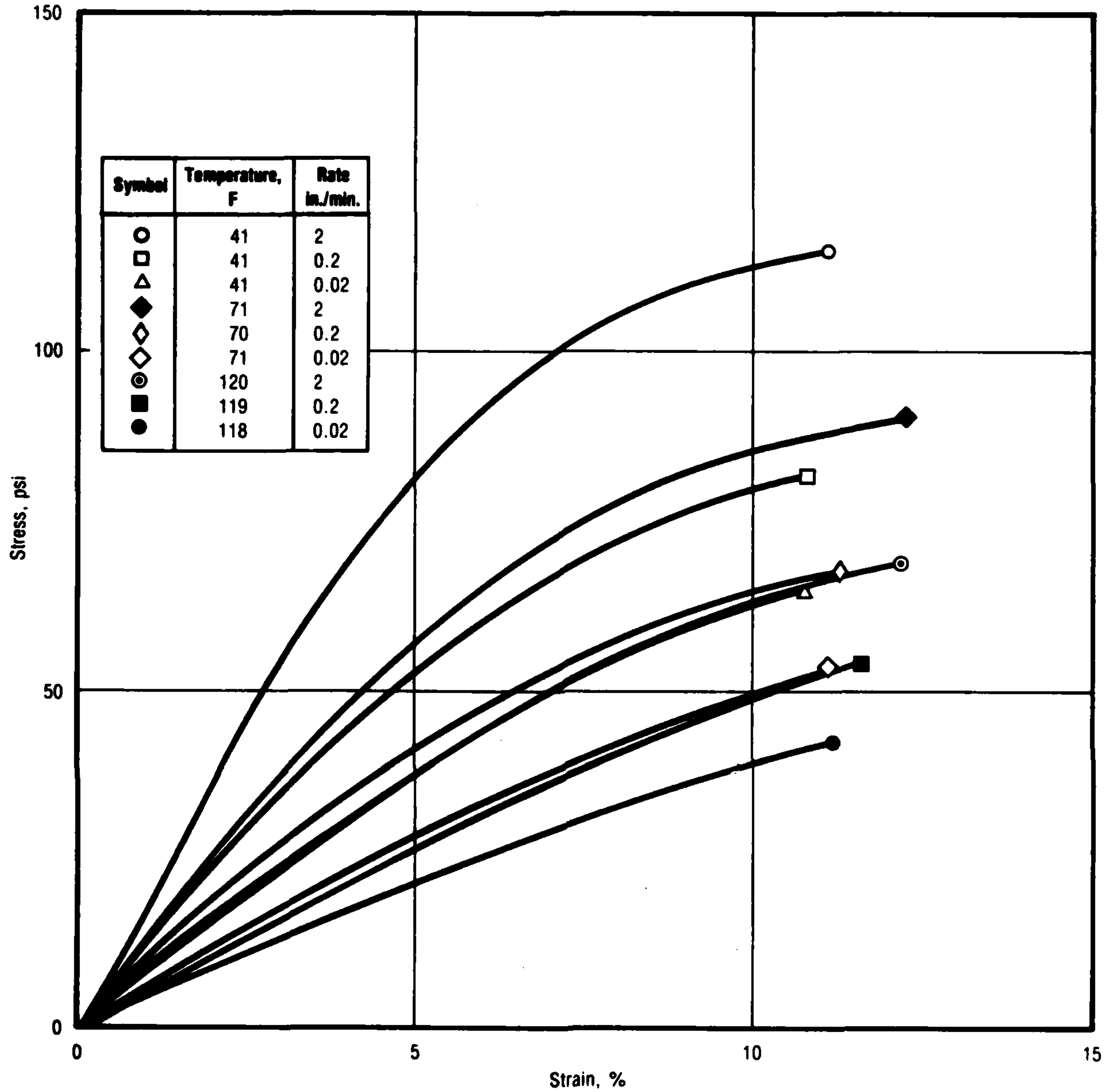

Figure 63. Biaxial Constant Rate Data for UTP-19,360B

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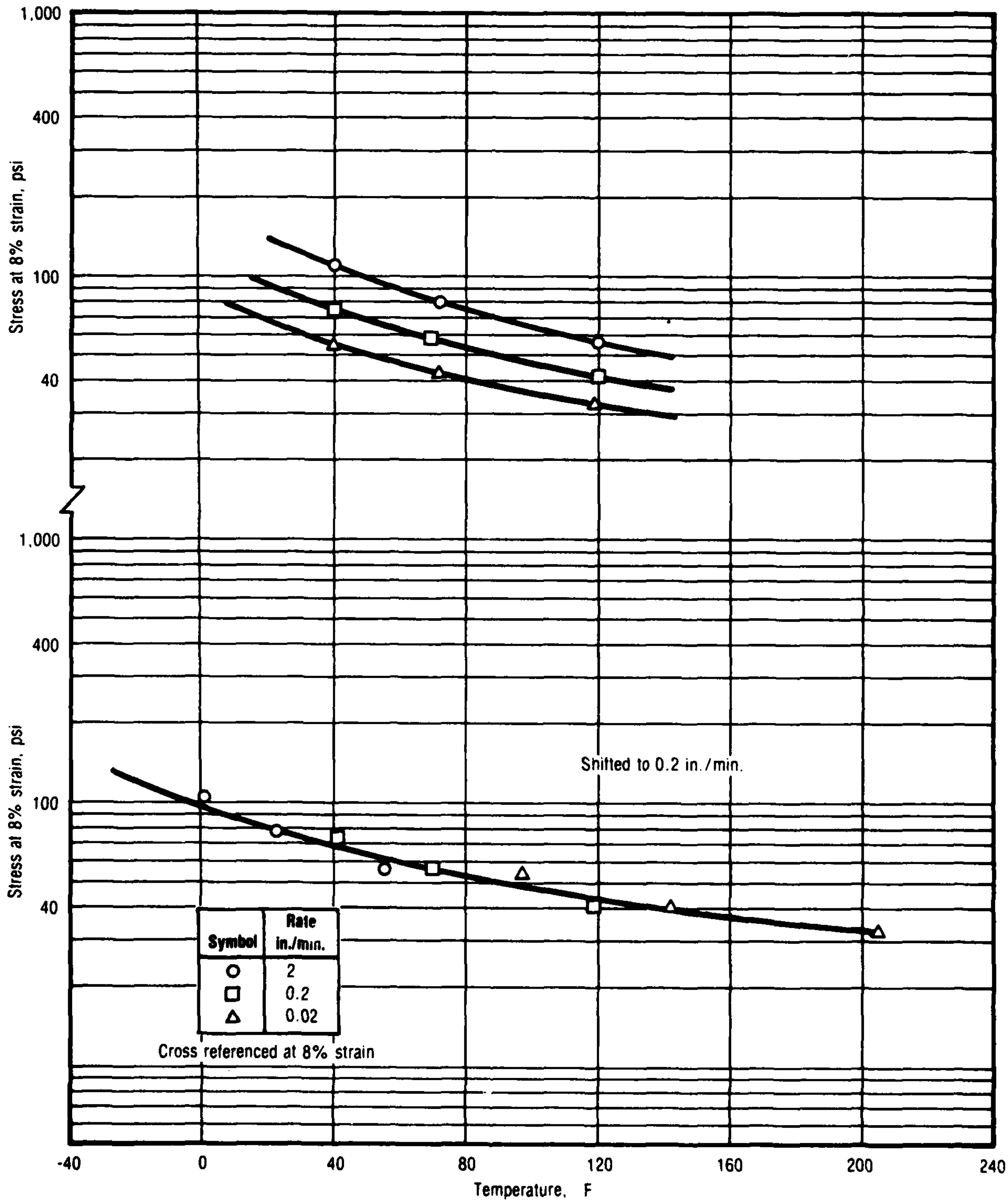

Figure 64. Test No. 14 - Biaxial Constant Rate Data for UTP-19,360B
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TABLE 34. COMPARISON OF UNIAXIAL, BIAXIAL, AND SHEAR TEST DATA FROM PHASE III

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Sample	Temperature, F	Rate, in./min.	Strain Rate, in./in./min.	UTP-3001		UTP-19,360B	
				Strain, %	Stress, psi	Strain, %	Stress, psi
Uniaxial	70	1	0.1667	10.0	128	10.0	57.7
Adjusted to				5.8	86.8	5.6	38.9
Biaxial	70	0.2	0.160	10.0	148	10.0	65.0
Shear	70	0.2	0.2	5.8	23.3	5.6	14.3
Adjusted to			0.160		24.0		15.0

Stress Ratios for:	UTP 3001	UTP 19360B
Uniaxial/biaxial	128/148 = 0.86	57.7/65.0 = 0.89
Shear/uniaxial	24.0/86.8 = 0.28	15.0/38.9 = 0.39

4.0 THEORETICAL DEVELOPMENT

4.1 INTRODUCTION AND PRELIMINARY STUDY

Generally speaking, solid propellants may be considered as lightly cross-linked long-chain polymers, highly filled with coarse solid particles. They respond viscoelastically to the action of external stimuli, but certain aspects of their behavior cannot be reproduced by the classical linear or nonlinear theories of fading-memory materials. Thus, in recent years, much work has been concerned with the development of appropriate models to predict the mechanical response of solid propellants. A current trend is to express the observed response in terms of some measure of "damage" at the continuum level where damage is described as the difference between the observed response and that predicted by a fading-memory theory, like Linear Viscoelasticity. There is now sufficient experimental evidence to show that damage (References 13, 17, 20, 24, and 28) per se is a microscopic phenomenon associated with the initiation and growth of flaws, debonding between matrix and solid filler particles, and molecular chain scission. Although it is largely irreversible, damage is partially recoverable shortly after removal of the loading system. This recovery from damage is termed healing. It is clear that, depending on the propellant and service requirements, it may also have to be accounted for in a constitutive theory for solid propellants.

In the present program, two approaches to characterizing damage have been followed. In the first one, damage is treated as the algebraic difference between the measured stress and that predicted by Linear Viscoelasticity, so that:

$$\sigma_c(t) = \sigma(t) - \sigma_\ell(t) \tag{1}$$

in which σ_ℓ and σ_c are the linear-viscoelastic and correction terms, respectively, with σ, the measured stress. In the second approach, the difference between measured and fading-memory type stresses is handled through a stress-correction function in the following form.

$$\sigma(t) = C\,(\epsilon_{max},\ldots)\,\sigma_f(t) \tag{2}$$

The softening function (C) is made to depend on the past maximum strain or stress and $\sigma_f(t)$ represents an appropriate function of the fading-memory type stresses.

Broadly speaking, the current versions of models by M. Gurtin and M. Quinlan are of the type presented in equation (1) above, while those of R. Schapery, W. Hufferd and Swanson are of the form given by equation (2).

The following presents some experimental evidence on the type of nonlinearities exhibited by solid propellants, and briefly discusses the pioneering work of Mullins and Tobin in treating the large hysteresis observed in tire rubbers. Next, the theory of Linear Viscoelasticity is applied to predict the response of UTP-19,360B and UTP-3001 under various strain histories. The ensuing results are meant as a basis for comparing the propellant response as predicted by each of the candidate constitutive laws. This comparison should be most meaningful because each of the theories considered evolved from a set of modifications to Linear Viscoelasticity. Subsequently, the nonlinear theory of Farris (Reference 5) is presented. This theory was employed during the first phase of the program to predict the response of TP-H1011 and to compare the results with those of the other five constitutive laws. Finally, a detailed description is given of each of these five stress-strain relations. This includes the original concept of the models, their current versions, comparisons of predicted and measured stresses for a variety of strain histories, and some pertinent guidelines for characterizing solid propellant according to each theory.

4.1.1 Experimental Background

The complex behavior of solid propellants, as well as some attempts at developing usable stress-strain laws for these materials, are well documented in References 3 through 31. It is shown there that a given deformation process causes a change in the response properties of solid propellants, for instance a drop in the relaxation modulus. As stated before, this deviation from some

expected response is what has been called damage. It is evidenced as phenomenological macroscopic changes that are caused by undefined, but real, irreversible or partially reversible microscopic changes. Polymer bond breakage, vacuole formation in the polymer matrix, dewetting between the polymer matrix and solid filler particles, microcracking, etc., are among the possible microscopic causes of observed permanent-memory effects in propellants.

Studies on uniaxial solid propellant samples have indicated that these materials exhibit large hysteresis even at small strains. These studies have also revealed that the state of damage in solid propellants is determined primarily by the maximum strain or stress undergone during the loading histories.

The typical nonlinear hysteresis and permanent-memory effects exhibited by solid propellants are illustrated in Figure 65. A series of finite-duration, variable-strain-level ramp pulses were used to obtain the propellant response subsequent to a given damage history (References 12 and 13). All ramps had the same initial moderate rise rate, with two exceptions to be noted later, and all ramps had the same very slow decline rate.

Observations of the load on the specimen after returning to its original length (zero strain) showed that it took approximately 30 min for the stress to relax to zero.

A series of tests were run on a 1/4 x 1/4 x 4-in. tab-end sample. The virgin specimen was initially strained to a level of 7.04% and allowed to relax to achieve a rest-state condition. The first part of the testing is shown in the lower half of Figure 65 (curves A-H) and the last part in the upper half (curves H-M).

Curve A shows the load response to this first pulse. The specimen was then subjected to four successive ramp strain pulses ranging from ϵ^o = 3.82% to ϵ^o = 6.34%. There was a rest period allowed between each pulse. The results are shown in Figure 65 as curves B through E.

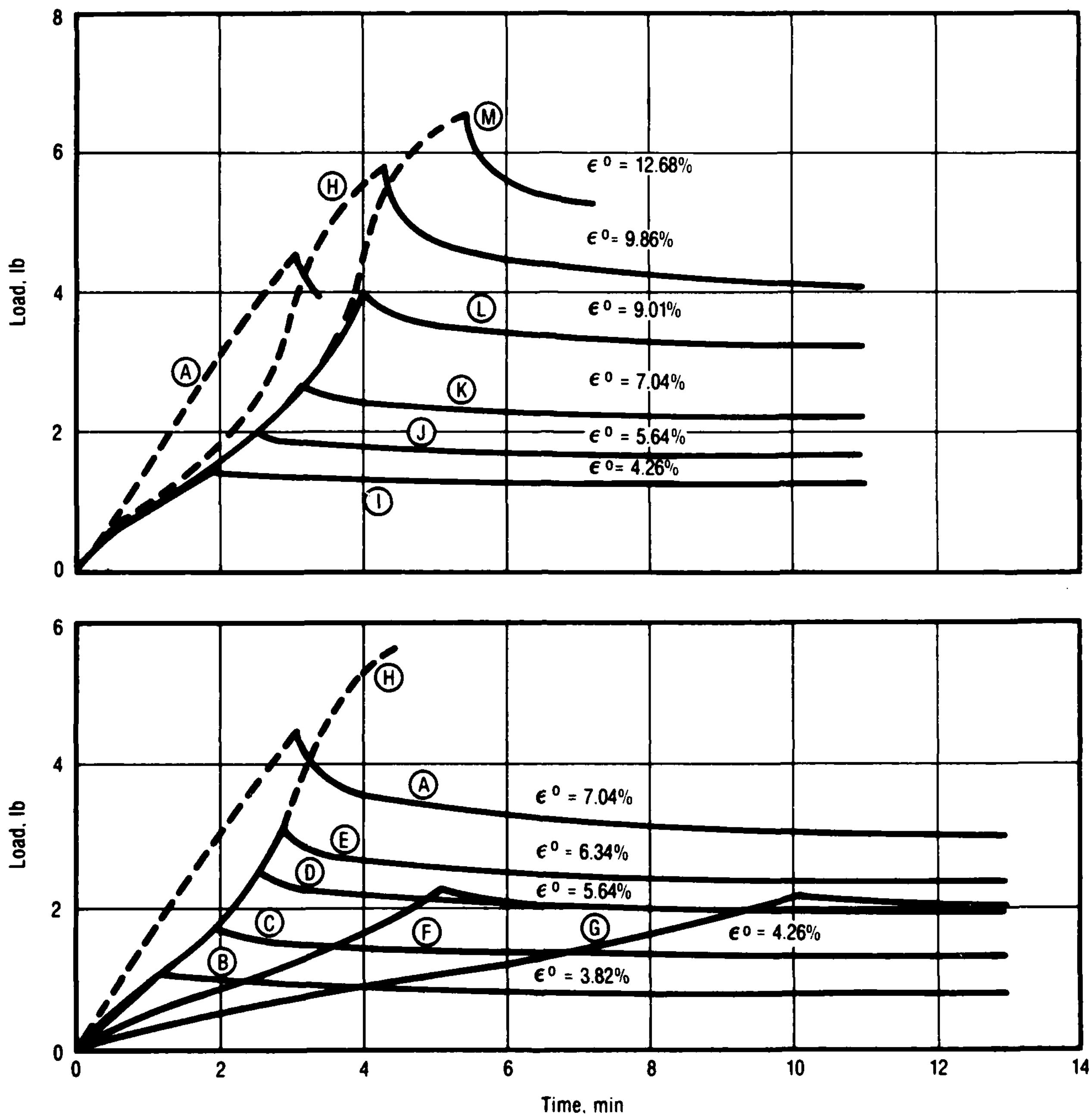

Figure 65. Relaxation after Damage

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Two aspects of the propellant's behavior are worth noting. First, during the constant strain rate portion of the ramp, each successive load-time curve is essentially identical. This indicates that the "new material" has the same nonlinear rate-dependency under repeated strain conditions as long as the strain

levels are below the previous maximum strain of ϵ^o = 7.04%. Second, the relaxation portions of the curves are essentially homologous, indicating that a viscoelastic relaxation process is taking place.

Curves F and G present the results of two additional tests at two successively lower strain rates where the sample was loaded to 5.64% strain each time. A strong rate dependency is observed during the rise portion of the ramp; however, curves F and G rapidly rejoin curve D indicating that the material is behaving in a viscoelastic fading-memory fashion.

The specimen was next subjected to a ramp strain pulse reaching a higher strain level (ϵ^o = 9.86%) than the maximum 7.04% previously experienced (Figure 65, curve H). The first part of curve H repeats the loading ramp portion of curves B-E to indicate the same "new material" rest-state. Note that the load-time curve returns to the initial or virgin constant strain rate curve once the previous maximum strain (7.04%) has been passed.

Subsequently, the specimen was strained with the ramp pulse to four different strain levels less than 9.86% (ϵ^o = 4.26%, 5.64%, 7.04%, and 9.01%), as shown in curves I through L. The results show that a new rate-dependency has developed (compare the rising portions of I through L with the rising portion of H). Thus, another "new-material" rest-state has been produced as a result of the second maximum strain level of 9.86%. Lastly, the specimen was strained to another new maximum of ϵ^o = 12.68% as shown in curve M. It again appears that it returned to the virgin undamaged curve once the 9.86% strain level was exceeded.

The above experimental evidence suggests that the form of the constitutive equation should remain unchanged with respect to the material's current rest-state. This condition should remain as long as the damage is unchanged (i.e., the ϵ_{max} is unchanged during its subsequent strain histories).

Figure 66 shows a replot (curves N and O) of some of the results just discussed. After an initial maximum strain (7.04%) the specimen was allowed to

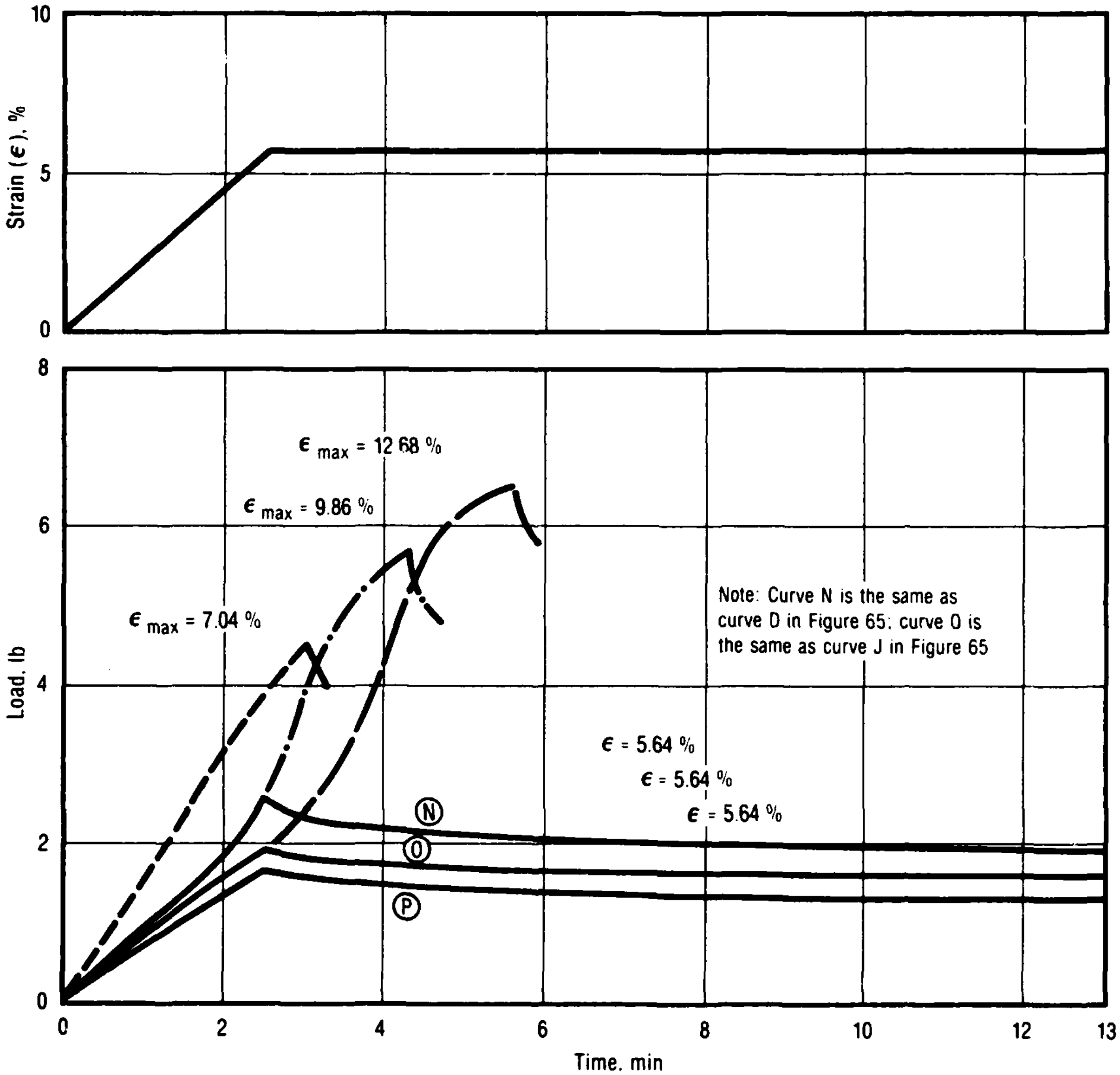

Figure 66. Relaxation after Damage

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return to a rest-state and then strained to a value of ϵ^o = 5.64%, with the result shown as curve P. These three identical strain history tests of three different material states indicate that the higher the state of damage (primarily ϵ_{max}), the softer the material response upon subsequent testing.

In addition, other experimental studies have pointed out the importance of healing effects, load duration, and initial strain rate (References 12, 13, 14,

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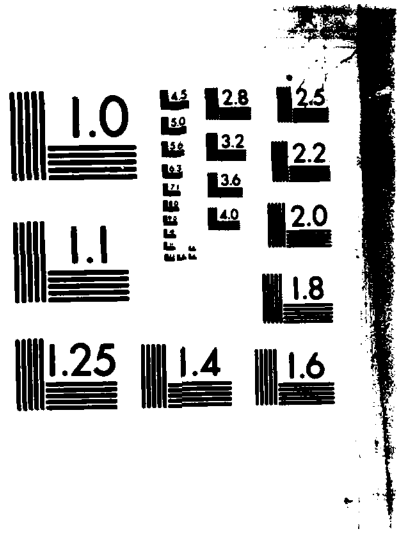

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and 15). Finally, it is important to note that the behavior of solid propellant, depicted in Figures 65 and 66, is similar to that exhibited by rubber. The nonlinear uniaxial stress response of rubber, with and without carbon black filler and in the absence of time effects, was characterized quite well by Mullins and Tobin (Reference 27) with equation (3).

$$\epsilon = \epsilon_u F \tag{3}$$

where:

ϵ = engineering strain. The Mullins-Tobin model is not limited to small strains.

$\epsilon_u = \epsilon_u(\sigma)$ = strain as a function of engineering stress for the polymer without filler and without damage. The characteristic shape of this function is shown in Figure 67.

$F = F(\sigma_{max}, N)$ = damage or softening function which depends on the maximum stress experienced by the rubber and the number N of loading and unloading cycles. F is not very sensitive to N, but depends strongly on any hard filler particles that may be present.

A large amount of rubber data can be predicted by means of this equation when the samples are not allowed to rest between cycles. Recovery or healing occurs as a function of the rest time. Therefore, healing would have to be considered in an accurate characterization of rubber.

Introducing the inverse of $\epsilon_u = \epsilon_u(\sigma)$, equation (3) may be put in the form:

$$\epsilon = f\ (\epsilon/F) \tag{4}$$

which shows that F (where $F<1$) is a strain-magnification factor. The ratio ϵ/F is interpreted by Mullins and Tobin to be the average strain in the rubber phase of a hard particle-filled rubber. Without damage in a highly-filled rubber, $F<<1$. As the rubber is cycled between the strains $\epsilon = 0$ and $\epsilon = \epsilon_{max}$, the ratio ϵ/F at any strain decreases, and therefore the stress decreases. The shape of the

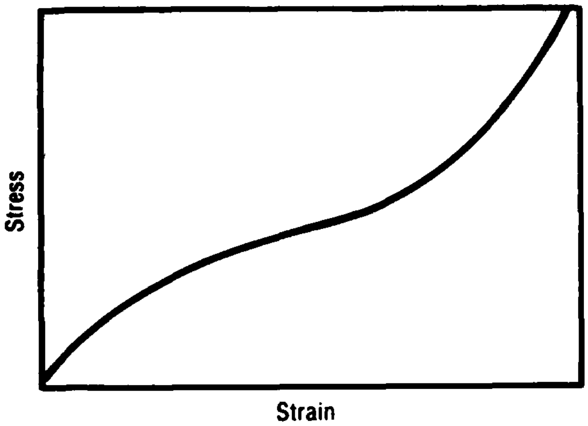


Figure 67. Stress-Strain Curve for Rubber

stress-strain curve is still as shown in Figure 67. It is similar to that for solid propellant after first-time loading. This fact and the ability of the model presented in equation (3) to reproduce a large amount of rubber data explains the great influence of the Mullins-Tobin approach on the development of nonlinear constitutive theories for solid propellants.

4.2 SELECTED THEORIES 22074

4.2.1 Linear Viscoelastic Constitutive Equation

4.2.1.1 Linear Viscoelastic Model

The one-dimensional stress-strain law for a thermorheologically simple linear viscoelastic solid may be expressed as:

$$\sigma(t) = \int_{0}^{t} E\,(S_t - S_\tau)\frac{d\xi}{d\tau}(\tau)\,d\tau \tag{5}$$

where:

σ = stress

ϵ = strain

$E(t)$ = relaxation modulus (PRONY series representation using a matrix solution for curve fitting data; CSD Data Analysis Procedure No. 7.3)

$S_t - S_\tau$ = temperature-shifted time, given by:

$$S_t - S_\tau = \int_{\tau}^{t} \frac{d\tau}{A_T\left[T\,(\tau)\right]} \tag{6}$$

and

a_T = time-temperature shift function, taken in the form:

$$A_T = \left(\frac{T_R - T_a}{T - T_a}\right)^m \tag{7}$$

in which T_R is the shift reference temperature, and both T_a and m are material parameters. The material parameters were obtained using CSD Data Analysis Procedure No. 7.4, which is a curve fit routine using Powell's algorithm.

The linear viscoelastic model was used to predict the response of UTP-19,360B and UTP-3001 under several strain histories. The corresponding results are included here as a basis against which to compare the stress predictions obtained using the nonlinear stress-strain laws considered in the program.

4.2.1.2 Stress Predictions

The measured response is compared against that predicted by linear viscoelasticity for UTP-19,260B in the following order (Figures 68 through 78).

The results for the lowest and highest constant-rate tests (Test No. 1) appear in Figures 68 and 69. Those for the dual-rate tests (high-to-low and low-to-high, Test No. 3) are shown in Figures 70 and 71. Figure 72 contains the comparisons for a saw-tooth strain history (Test No. 5) with increasing strain peaks and rest periods between cycles. The results corresponding to short- and long-duration similitude tests are presented in Figures 73 and 74. The predicted and measured responses for the three-step relaxation test (Test No. 13) are included in Figure 75. In addition, the time-temperature superposition principle is put to use with constant rate tests (Test No. 1) at 70, 40 and 123°F, as shown in Figures 76 to 78, respectively. Stress predictions for some of the same tests on UTP-3001 are shown in Figures 79 through 86.

4.2.2 R. Farris Nonlinear Theory for Solid Propellants

The work of R. Farris (Reference 5) was a major attempt at predicting the nonlinear response of solid propellants in rocket motor analyses.

Experience with Farris' stress-strain law at Chemical Systems showed that this theory could not predict the response of solid propellants under strain

(Text continued on page 200.)

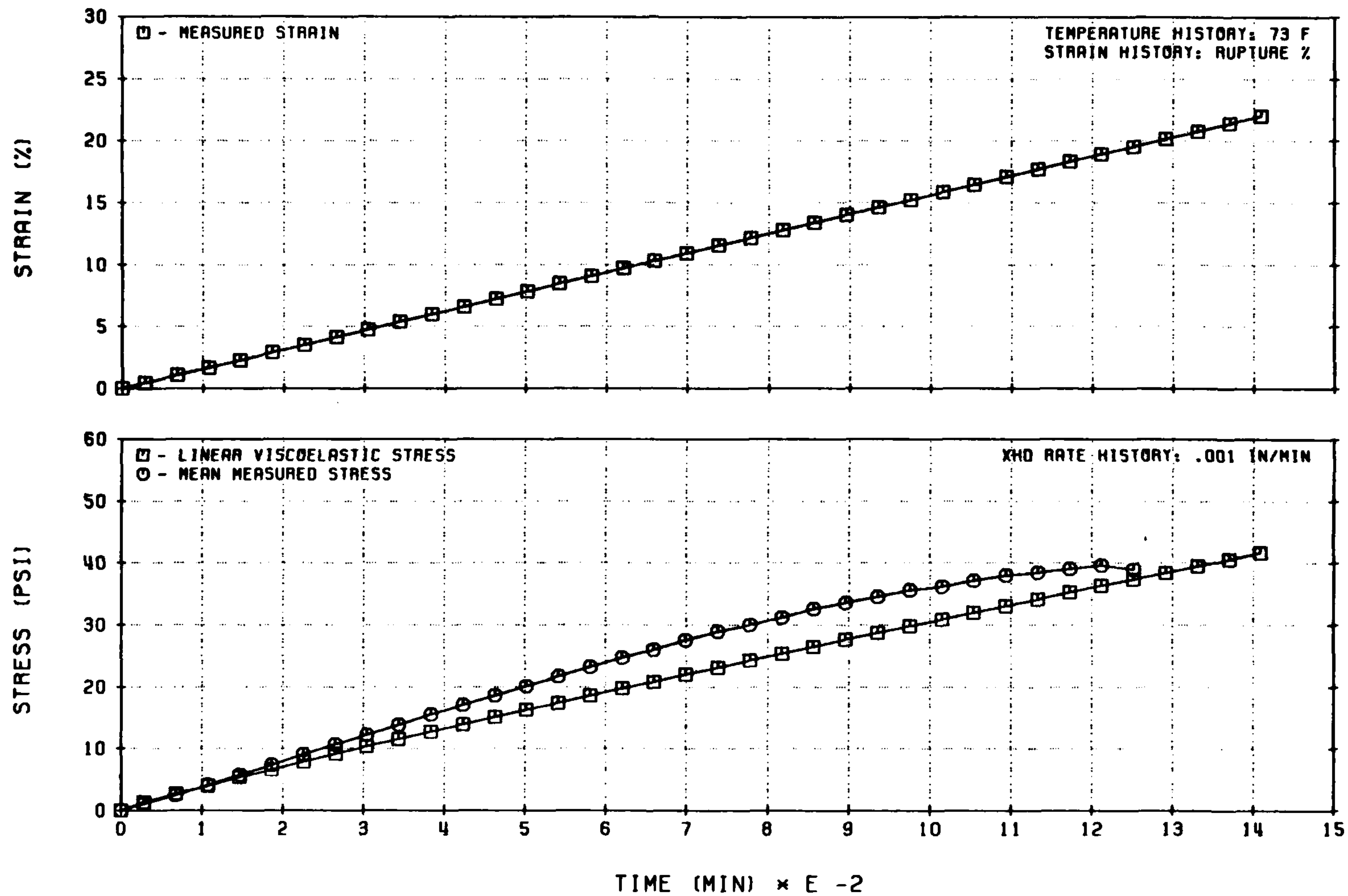


Figure 68. Linear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 Constant Rate Test History (Code No. 1)

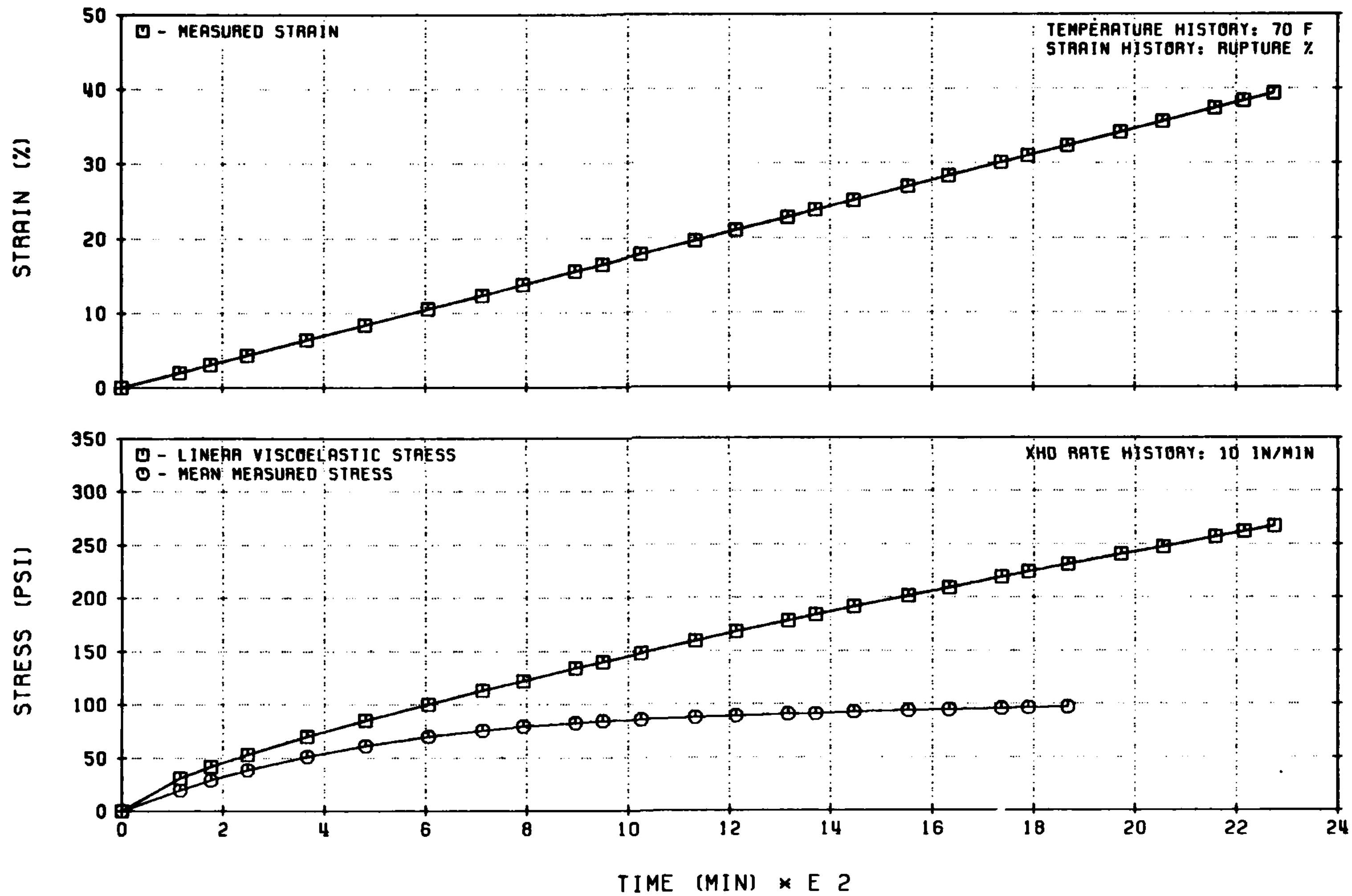


Figure 69. Linear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 Constant Rate Test History (Code No. 1)

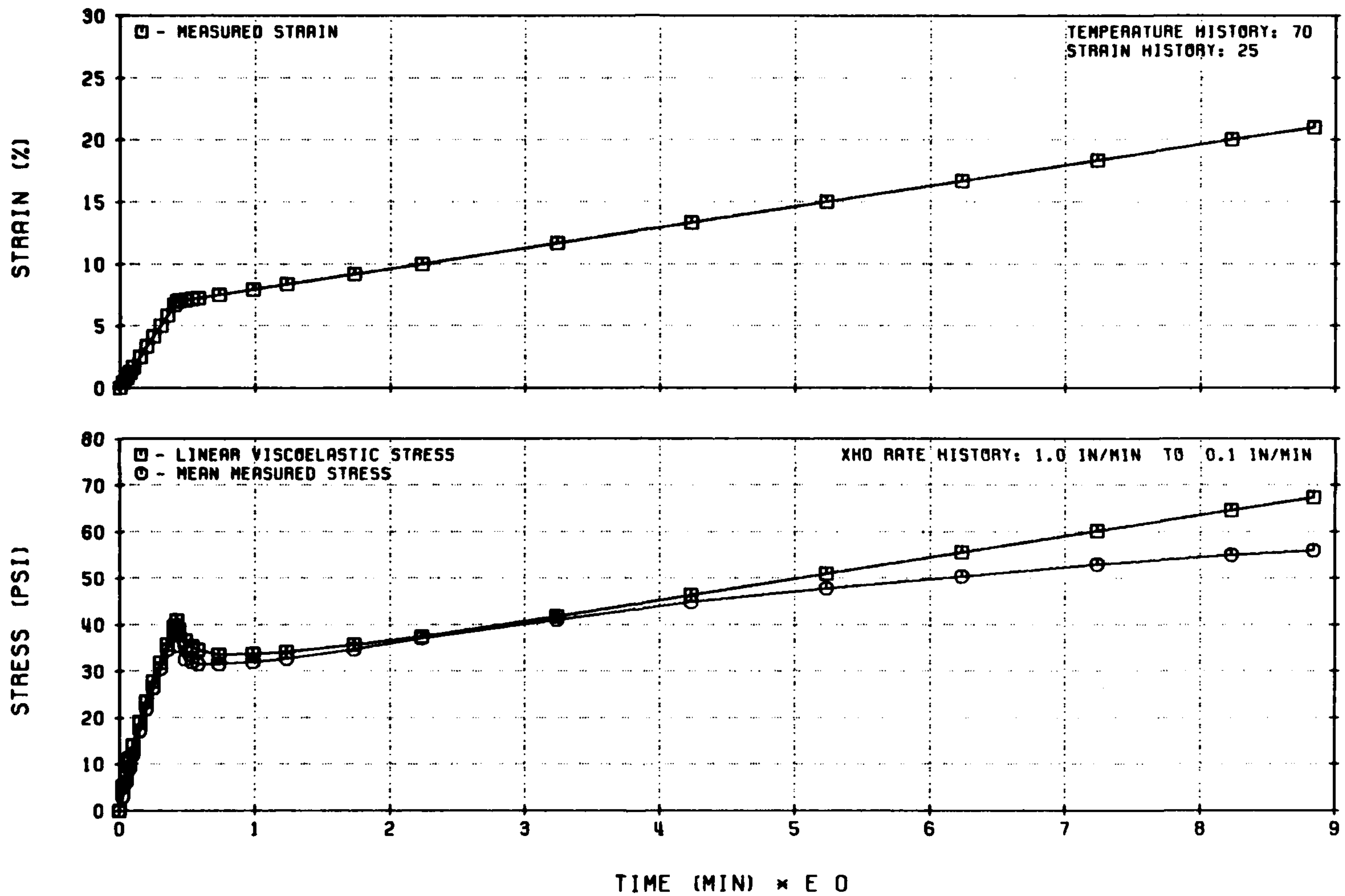


Figure 70. Linear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 Two Rate Test History (Code No. 3)

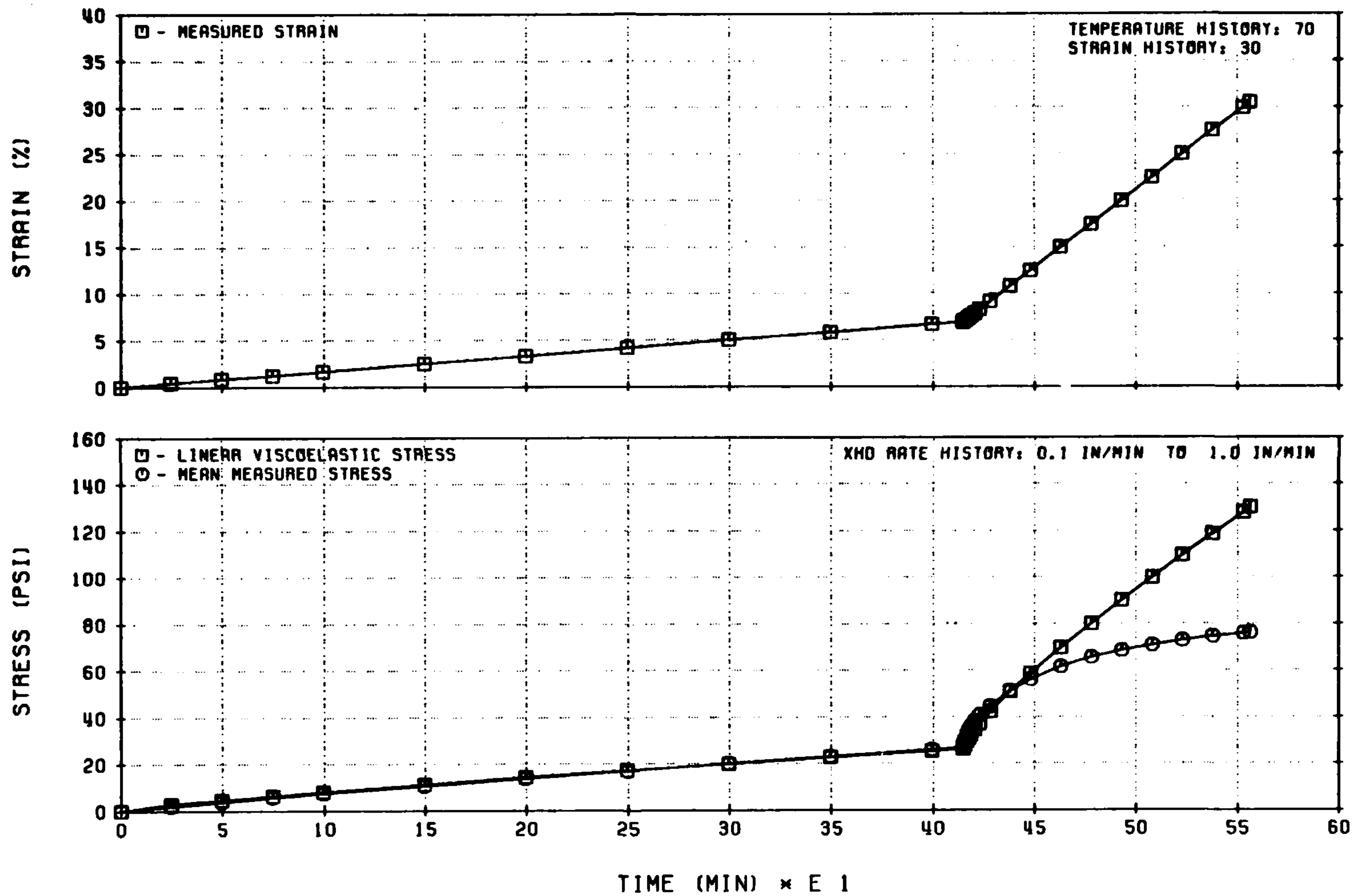


Figure 71. Linear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 Two Rate Test History (Code No. 3)

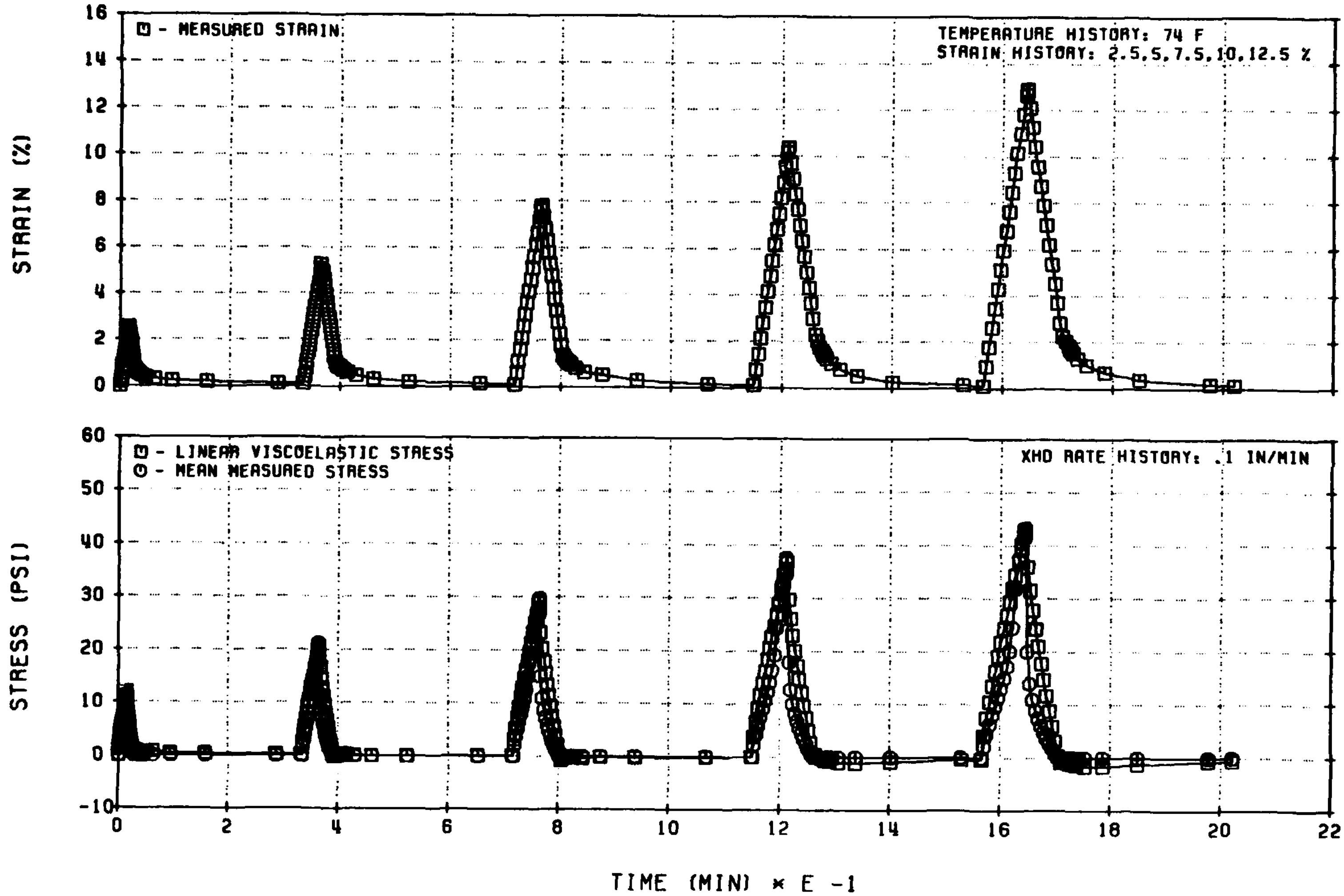


Figure 72. Linear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 Multiple Loading Test History (Code No. 5)

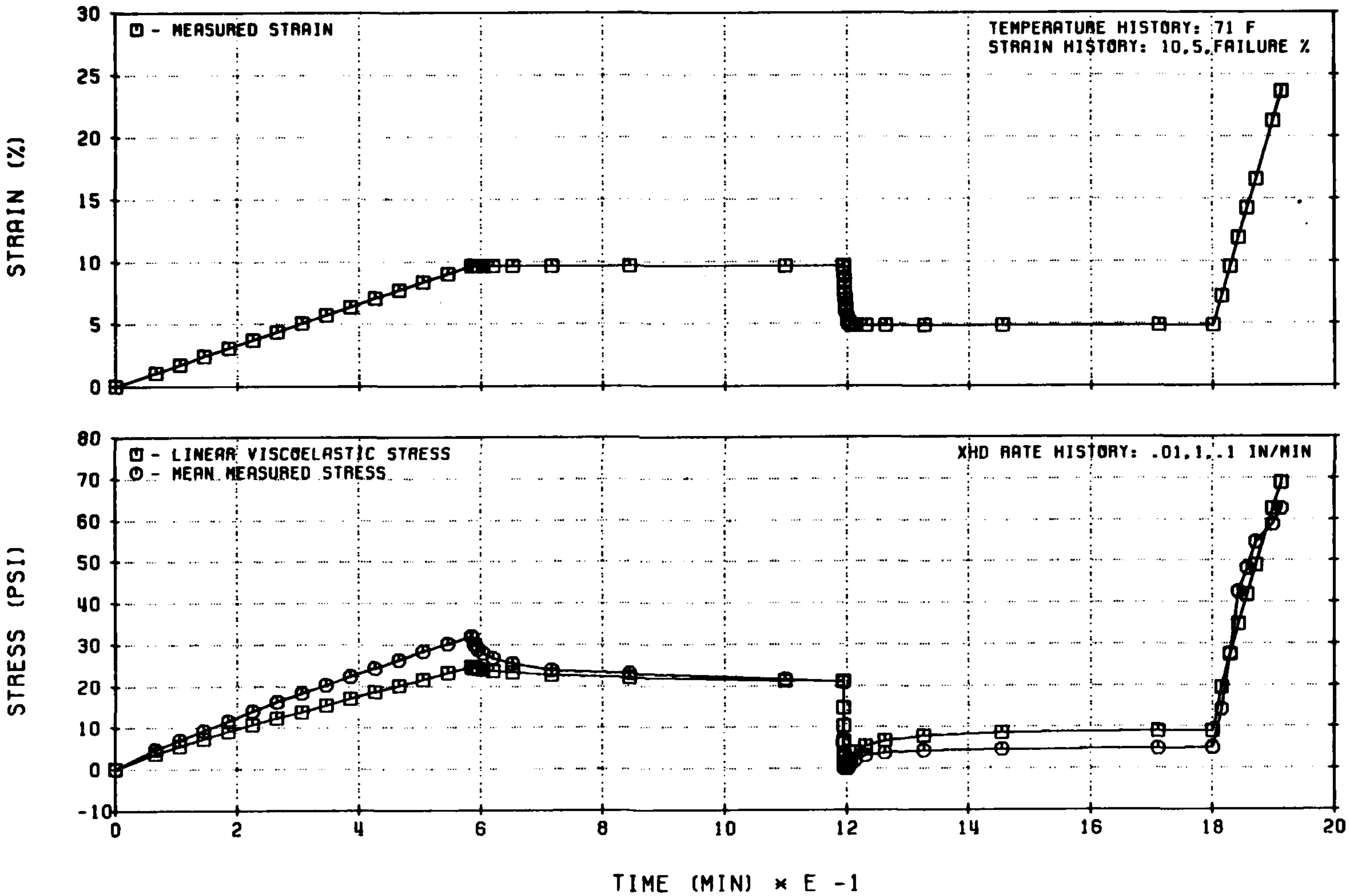


Figure 73. Linear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 Similitude Test History (Code No. 12)

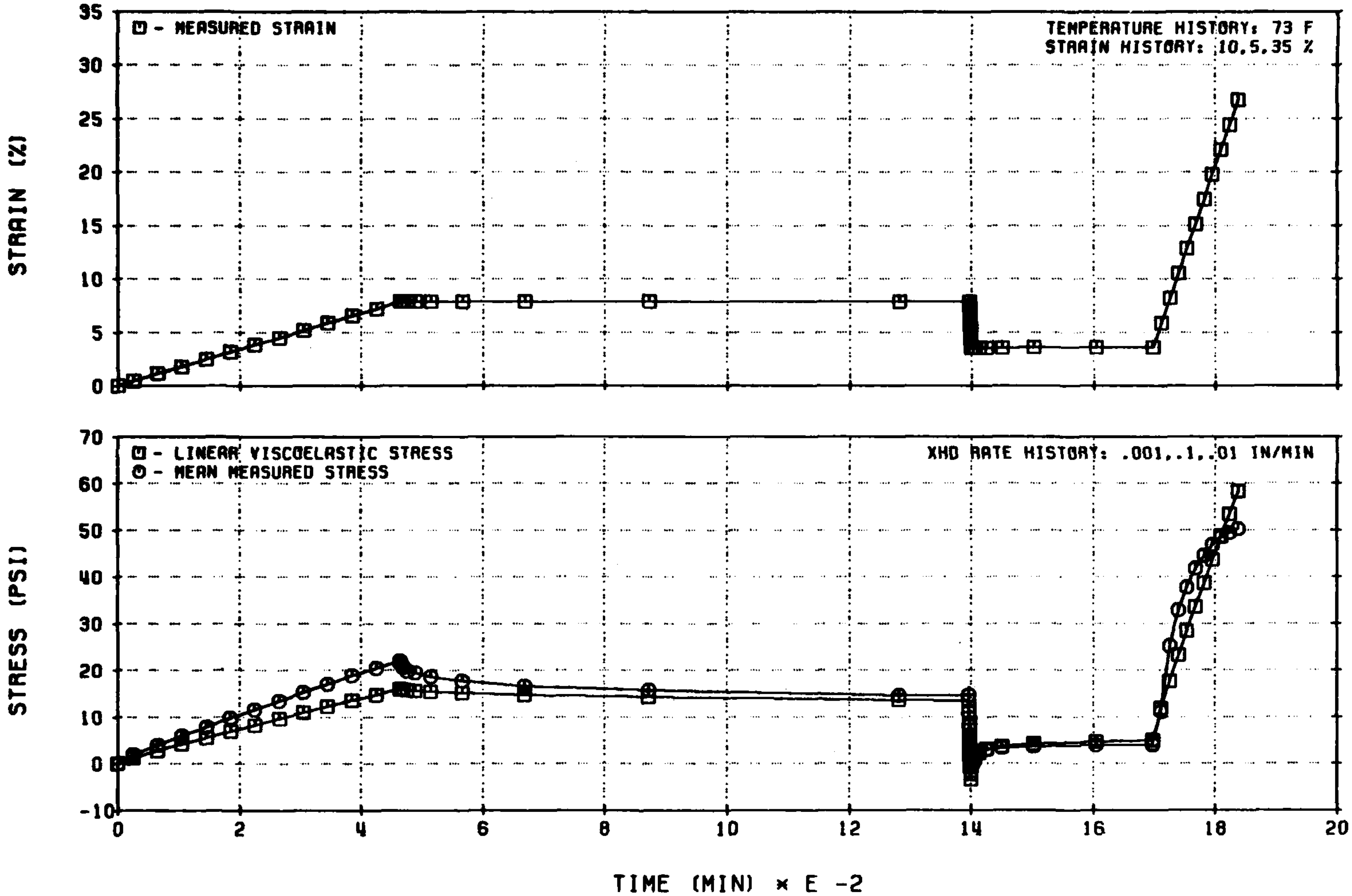


Figure 74. Linear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 Similitude Test History (Code No. 12)

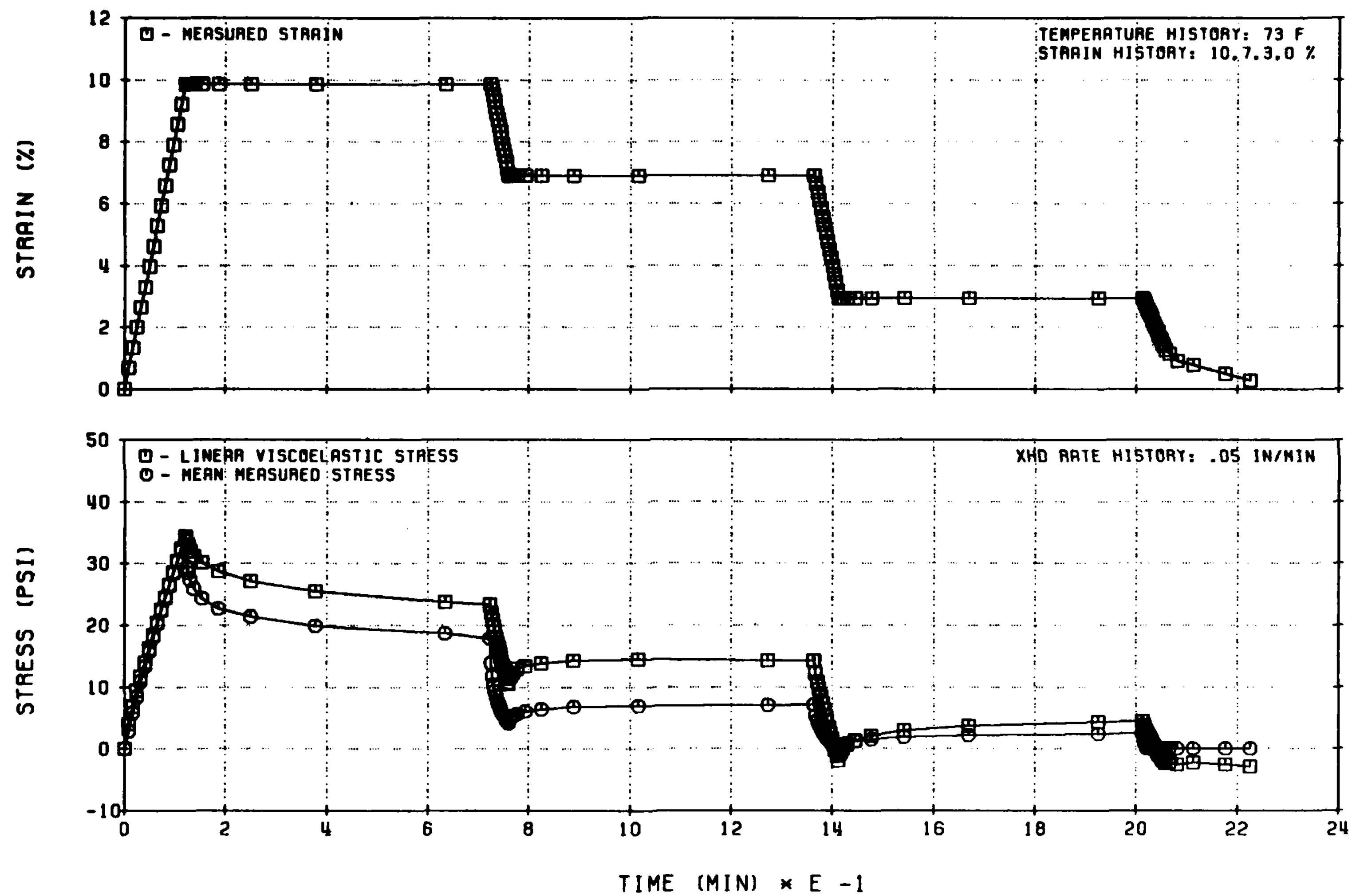


Figure 75. Linear Viscoelastic Stress Predictions for UTP-19,360B-400/1777
Three Step Relaxation Test History (Code No. 13)

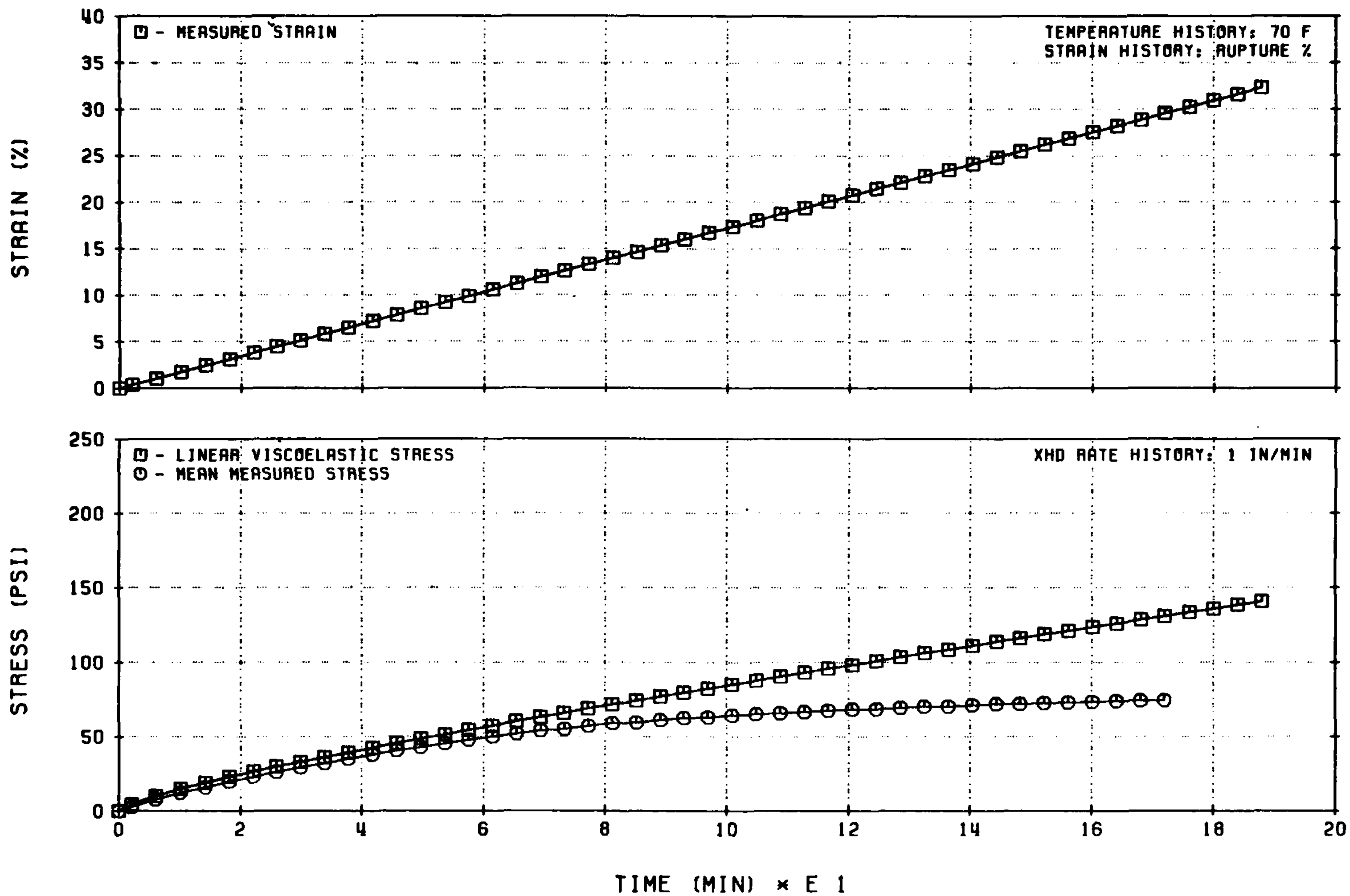


Figure 76. Linear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 Constant Rate Test History (Code No. 1)

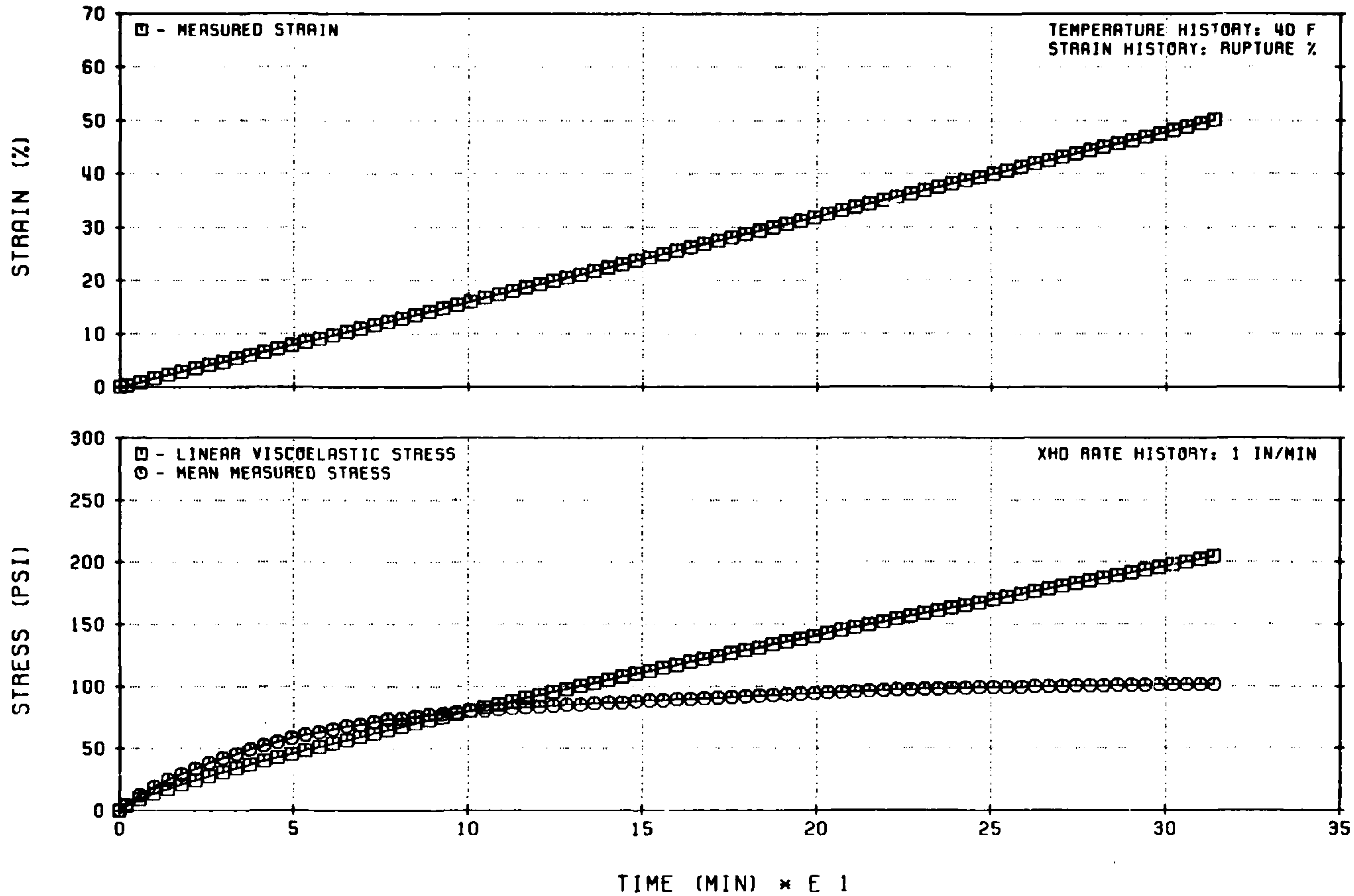


Figure 77. Linear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 Constant Rate Test History (Code No. 1)

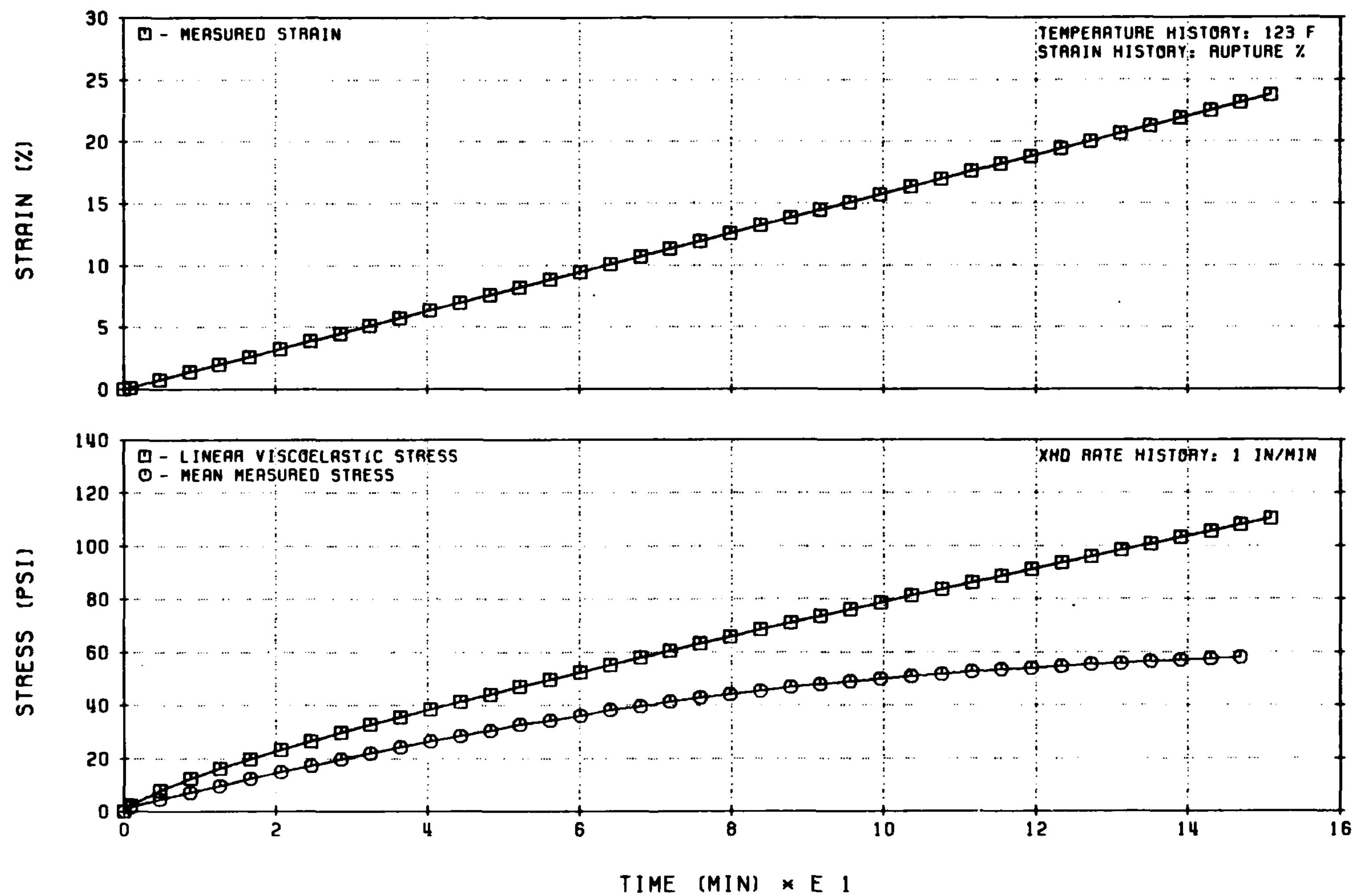


Figure 78. Lin?ar Viscoelastic Stress Predictions for UTP-19,360B-400/1777 Constant Rate Test History (Code No. 1)

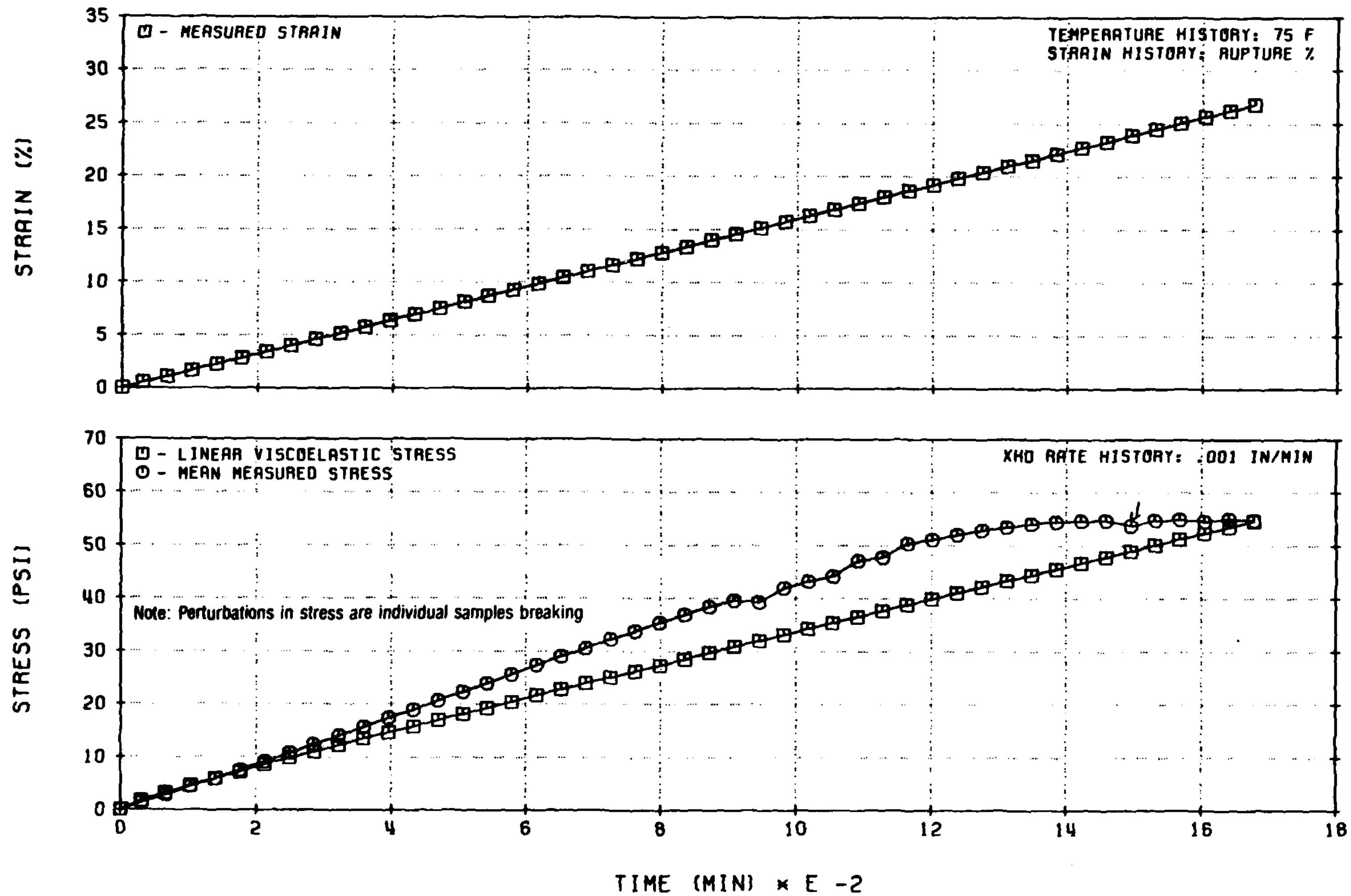


Figure 79. Linear Viscoelastic Stress Predictions for UTP-3001-750/7768 Constant Rate Test History (Code No. 1)

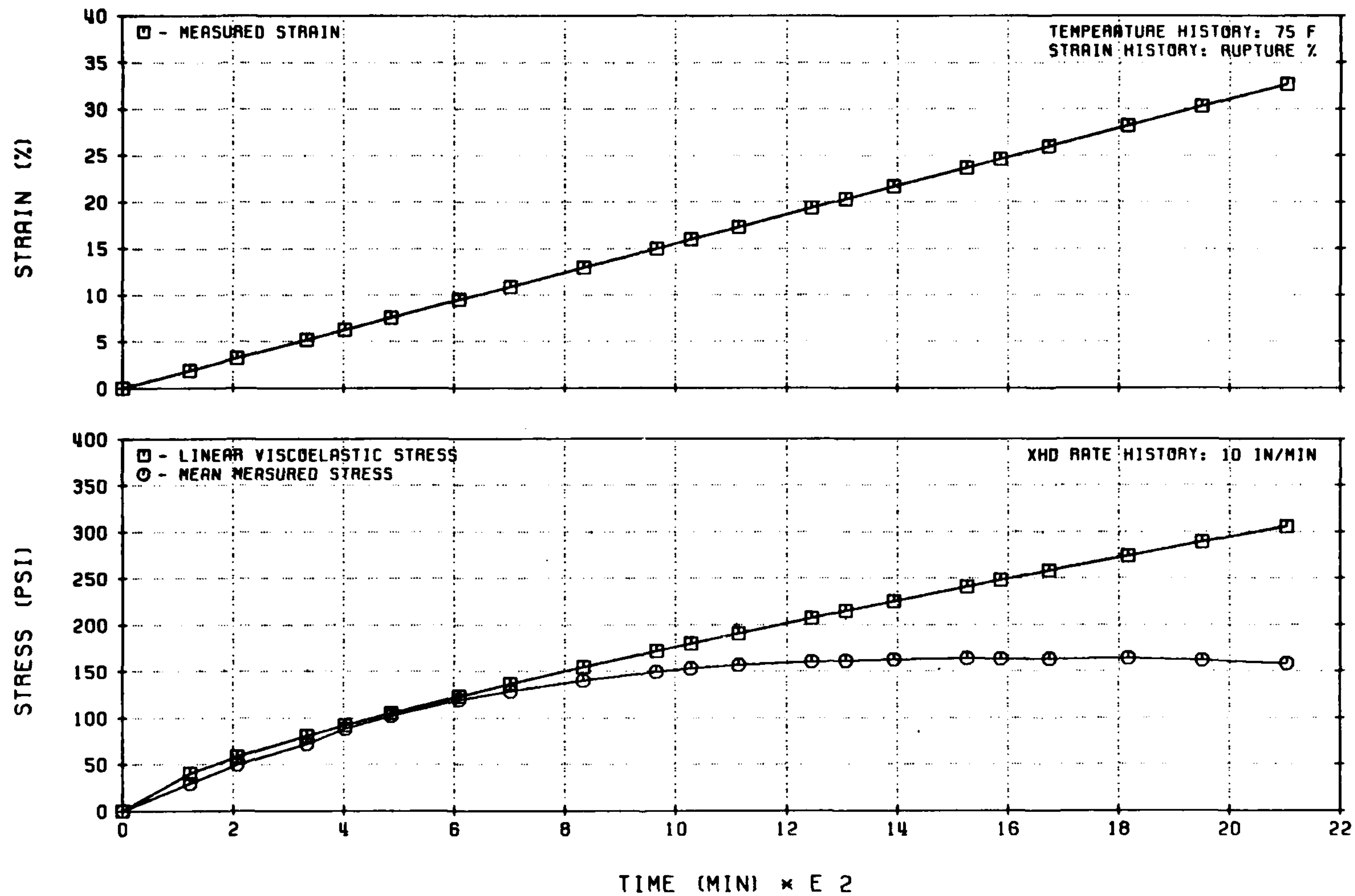


Figure 80. Linear Viscoelastic Stress Predictions for UTP-3001-750/7768 Constant Rate Test History (Code No. 1)

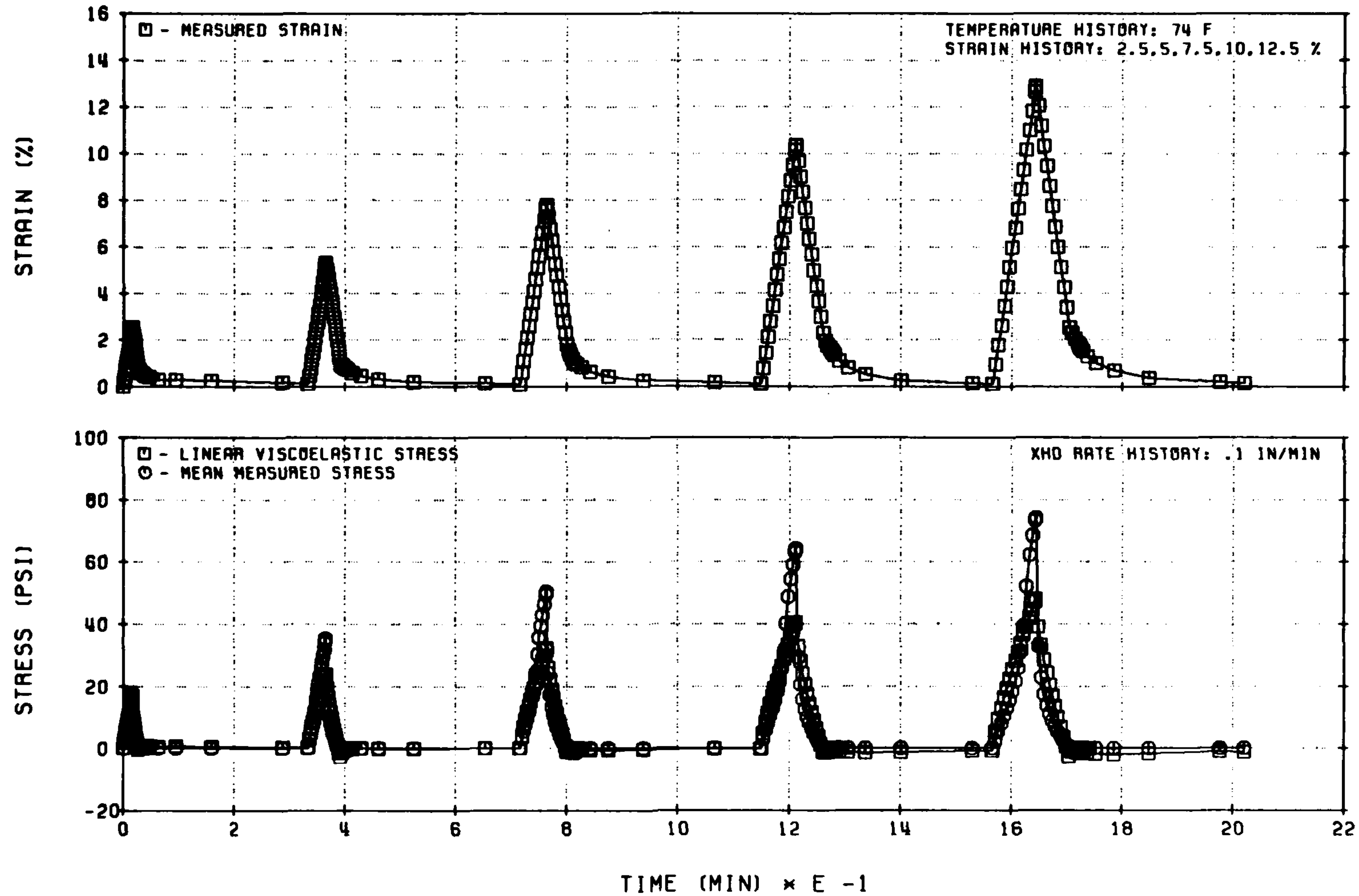


Figure 81. Linear Viscoelastic Stress Predictions for UTP-3001-750/7768 Multiple Loading Test History (Code No. 5)

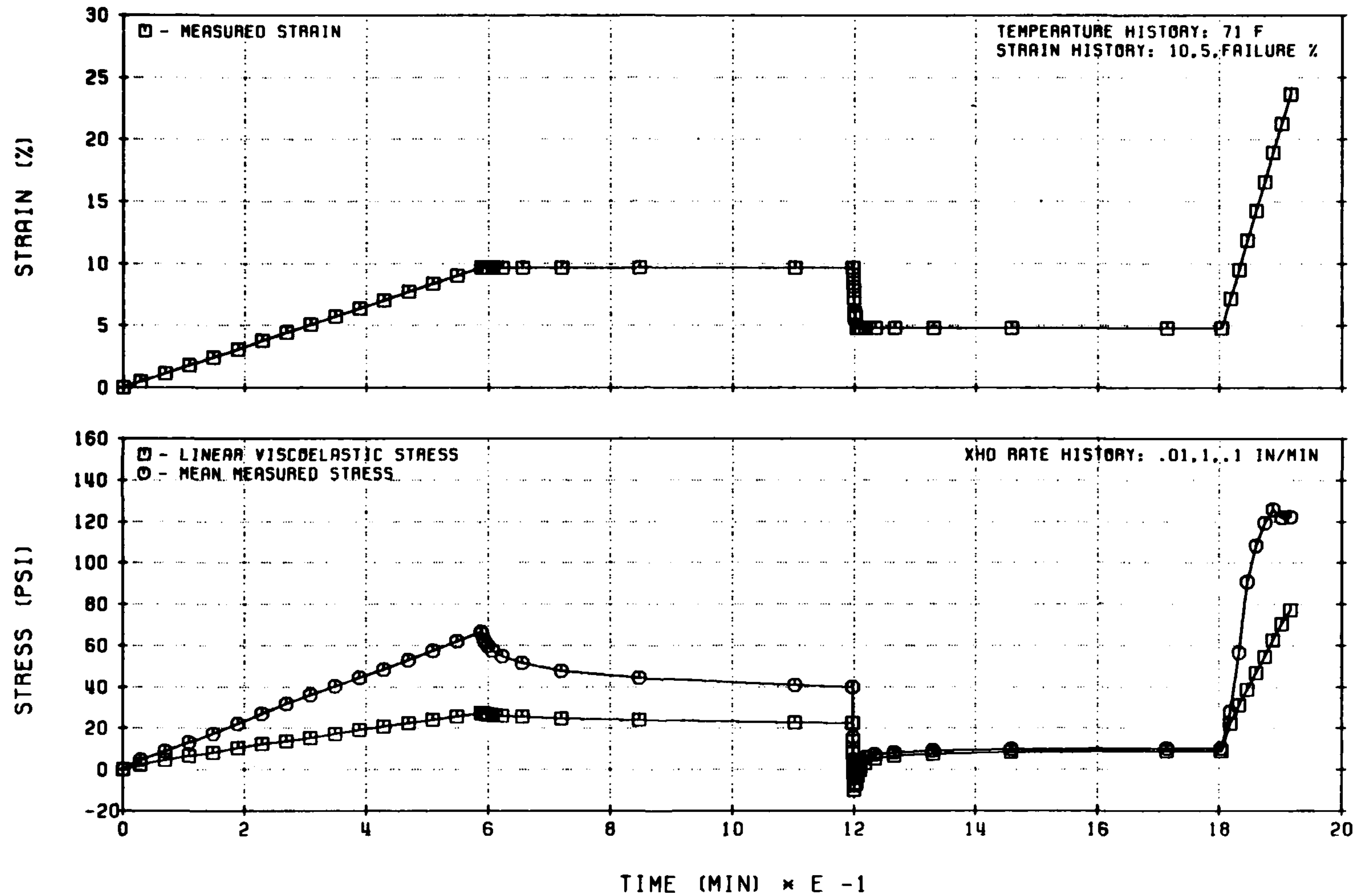


Figure 82. Linear Viscoelastic Stress Predictions for UTP-3001-750/7768 Similitude Test History (Code No. 12)

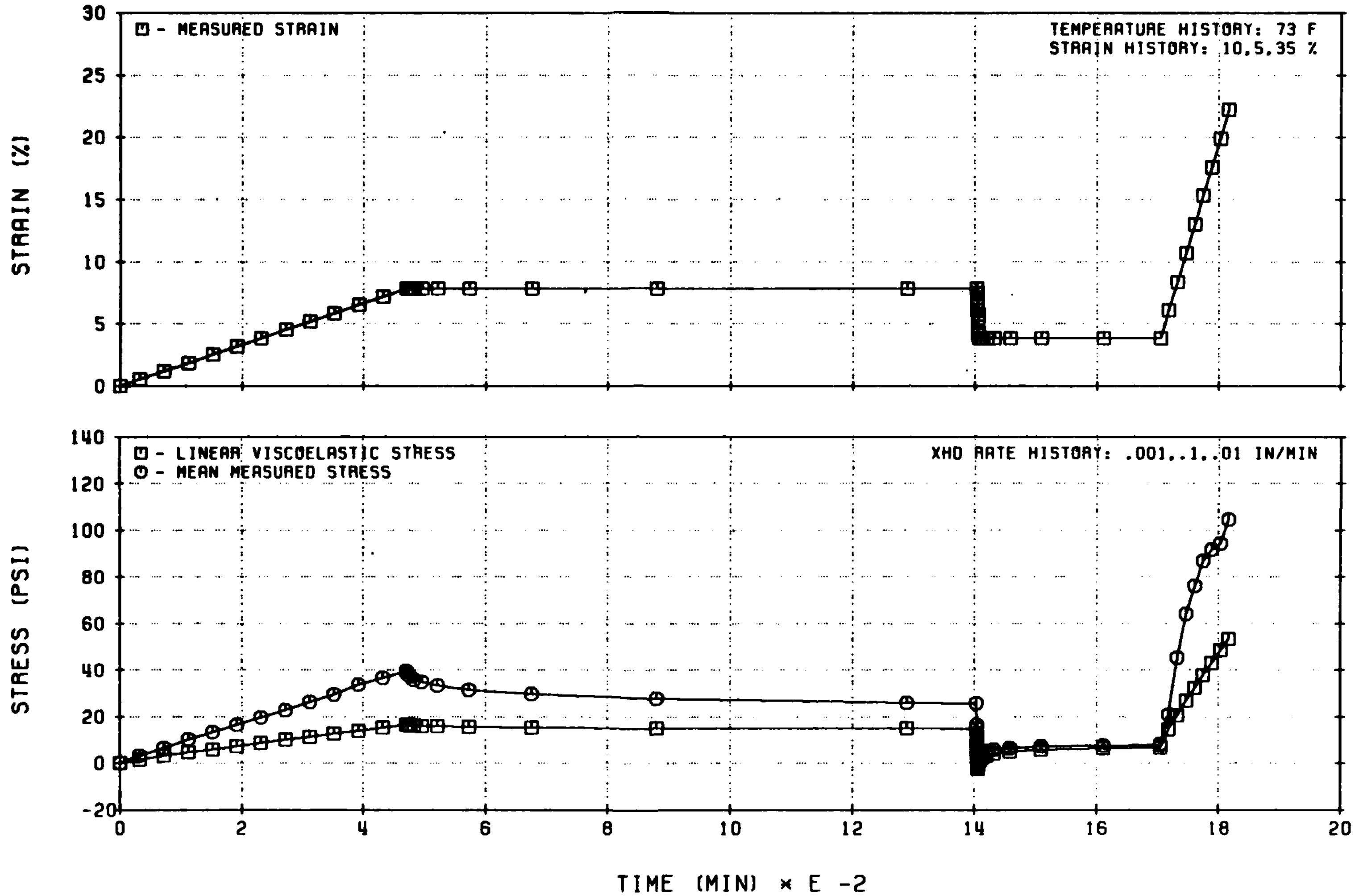


Figure 83. Linear Viscoelastic Stress Predictions for UTP-3001-750/7768 Similitude Test History (Code No. 12)

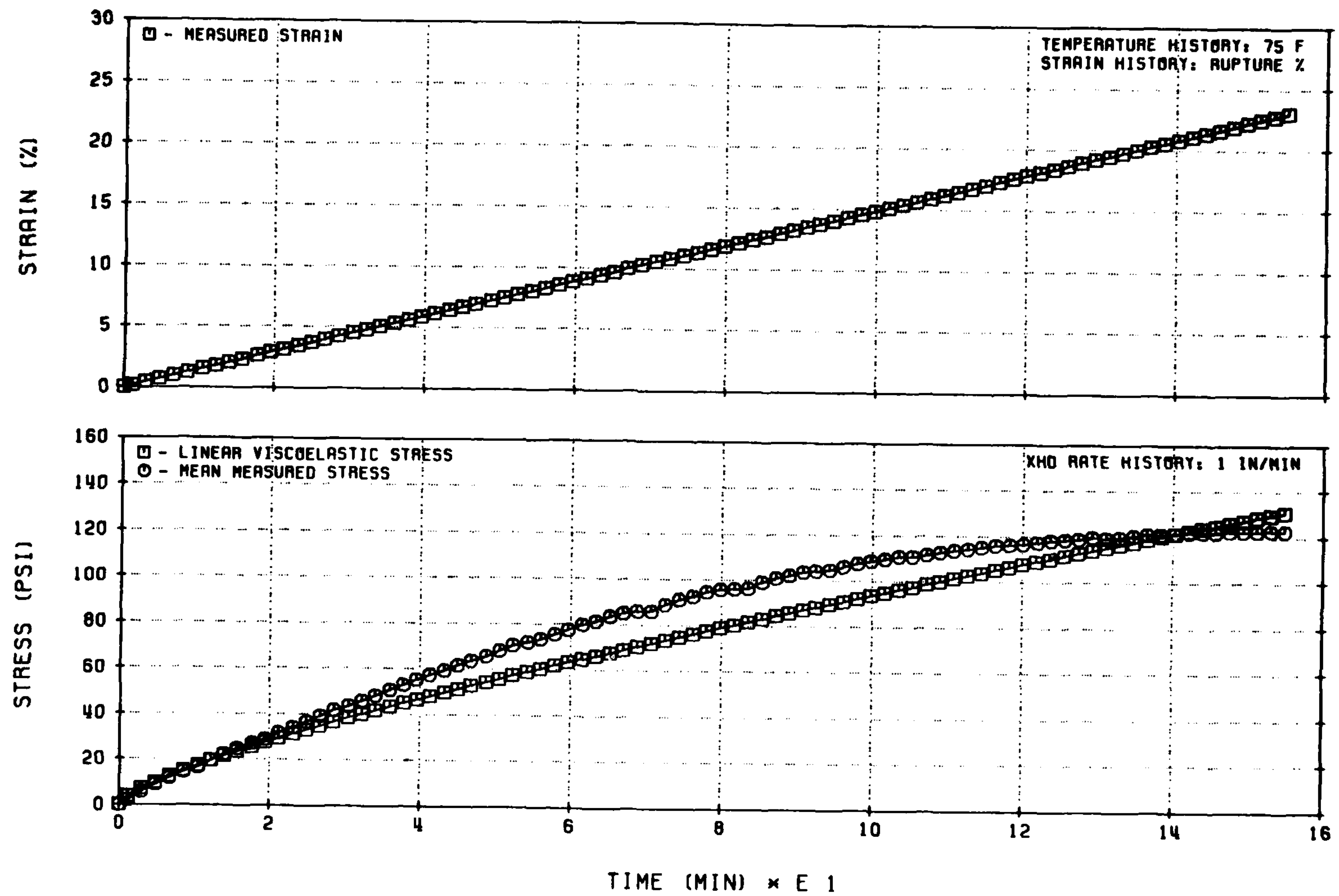


Figure 84. Linear Viscoelastic Stress Predictions for UTP-3001-750/7768 Constant Rate Test History (Code No. 1)

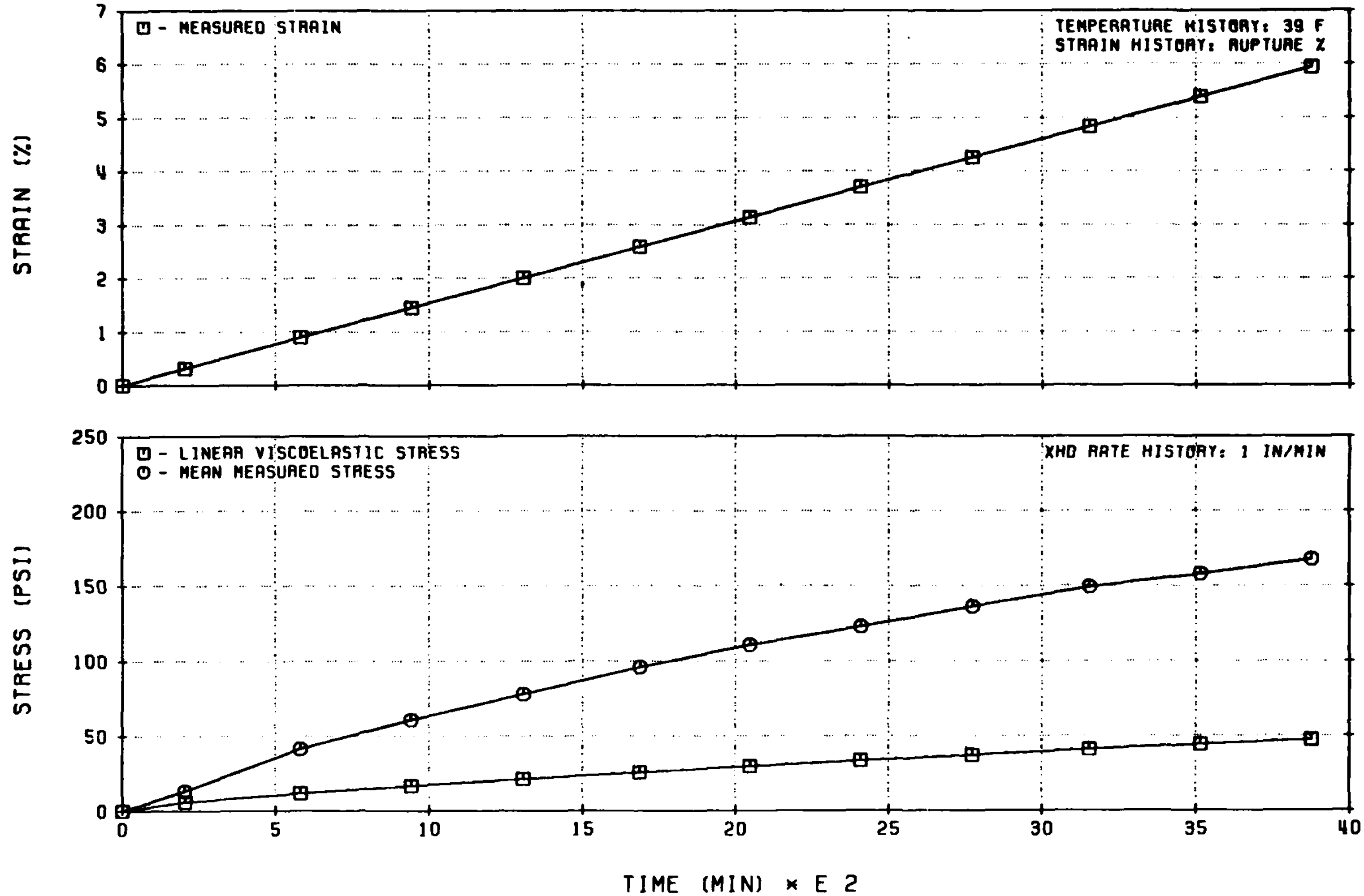


Figure 85. Linear Viscoelastic Stress Predictions for UTP-3001-750/7768 Constant Rate Test History (Code No. 1)

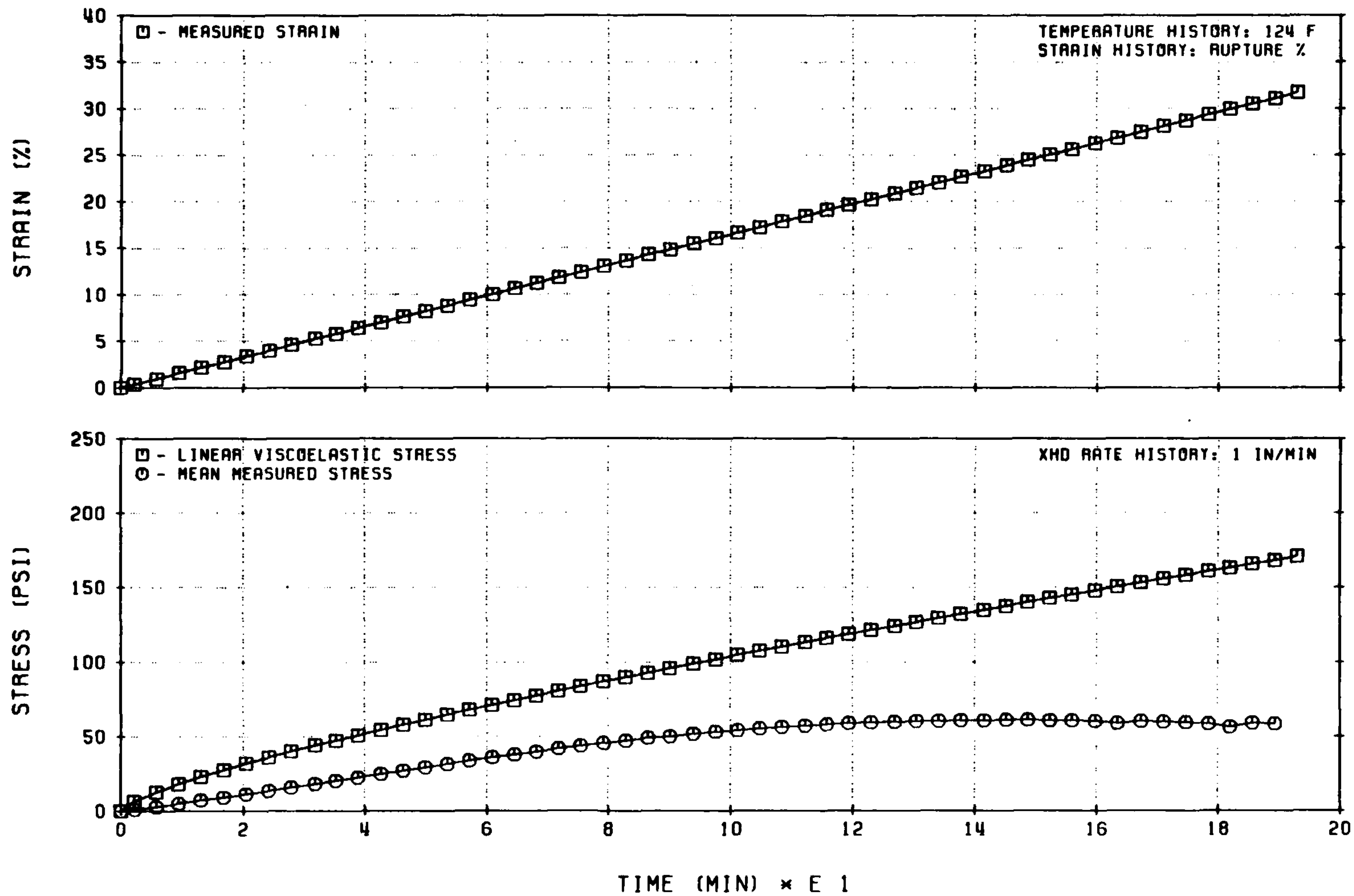


Figure 86. Linear Viscoelastic Stress Prediction for UTP-3001-750/7768 Constant Rate Test History (Code No. 1)

histories that were not included in the set used for material characterization. Although the predictions were generally acceptable for loading histories of the types included in such sets.

The nonlinear theory of Farris was considered in the first phase of the program and it was compared to the other five approaches originally proposed.

Farris postulated a model, based upon previous work on rubber elasticity, to account for the permanent-memory effects exhibited by many solid propellants under constant rate loading. This model presumes the existence of inhomogeneities in the local strain field between filler particles, a distribution of polymer chain lengths between filler particles, and a uniform failure strain for each polymer chain. This model has been successful in predicting the nonlinear permanent memory response of solid propellants before dewetting. The model predicts the same response in compression as in tension. This prediction is in agreement with experimental observations, although the molecular mechanisms contributing to the permanent memory response in compression are clearly different from those in tension.

Once dewetting occurs, the model is modified to account for vacuole formation and different results in compression and tension are expected. Farris presented the constitutive equation as the sum of an essentially time-independent bulk stress σ_B and a time-dependent deviatoric stress σ_{ij}^d, so that in general

$$\sigma_{ij}(t) = \sigma_B \delta_{ij} + \sigma_{ij}^d(t) \tag{8}$$

where δ_{ij} is the Kronecker delta equal to unity if $i = j$ and zero otherwise. The form developed for the deviatoric stress is

$$\sigma_{ij}^d(t) = e^{-BI_d/I_\gamma} \left\{ A_1 e_{ij}^d(t) + A_2 \left(\frac{I_\gamma}{\| I_\gamma \|_{p_2}} \right)^{m_2} e_{ij}^d(t) + \int_0^t A_3(t-\xi)\, \dot{e}_{ij}^d(\xi)\, d\xi + \left(\frac{I_\gamma}{\| I_\gamma \|_{p_4}} \right)^{m_4} \int_0^t A_4(t-\xi)\, \dot{e}_{ij}^d(\xi)\, d\xi \right\} \tag{9}$$

where

I_d = volume dilatation = $e_{11} + e_{22} + e_{33}$ for small strains

$$I_\gamma = \text{octahedral shear strain} = \frac{1}{3}\left[(e_{11} - e_{22})^2 + (e_{22} - e_{33})^2 + (e_{33} - e_{11})^2\right]^{1/2} \tag{10}$$

e^d_{ij} = deviatoric strain tensor

$B, A_1, A_2, A_3, A_4, M_2, M_4, P_2, P_4,$ = constants

and

$$\|I_\gamma\|_{p_i} = \left[\int_0^t \left| I_\gamma(\xi) \right|^{P_i} d\xi\right]^{1/P_i} \tag{11}$$

Equation (9) has been applied to reasonably complex deformation histories using unpressurized and pressurized uniaxial and biaxial test specimens. The agreement was not as good as would have been desirable, but it was still better than Linear Viscoelasticity. Time-temperature superposition was included in equation (9) by introducing a time-temperature shift factor, a_T, and redefining the L_p norm of equation 140 in the form:

$$\| I_\gamma\|_{p_i} = \left(\int_0^t \frac{\left| I_\gamma\ (\xi) \right|^{P_i}}{a_T(\xi)} d\xi\right)^{I/p_i} \tag{12}$$

Experimental data for simultaneous cooling and straining have been fit using equation (9) with the introduction of a time-temperature shift function a_T through equation (11). The justification for introducing an a_T in the above manner is not immediately obvious or adequately explained in the available literature.

To present the response to interrupted and cyclic constant strain rate tests, equation (9) was modified by setting $P_4 = \infty$ and $A_3 = -A_4$ so that:

$$\overset{d}{\sigma}_{ij}(t) = e^{-BI_d/I_\gamma} \Bigg\{ A_1 \overset{d}{e}_{ij}(t) + A_2 \left(\frac{I_\gamma}{\| I_\gamma \|_{P_2}} \right)^{m_2} \overset{d}{e}_{ij}(t) \tag{13}$$

$$+ \left[1 - \left(\frac{I_\gamma}{\| I_\gamma \|_\infty} \right)^{m_4} \right] \int_0^t A_3 (t - \xi) \overset{d}{e}_{ij}(\xi)\, d\xi$$

where:

$$\| I_\gamma \|_\infty = \max \left| I_\gamma(\xi) \right|, \quad 0 < \xi < t$$

The multiplier for the hereditary integral in equation (12) vanishes whenever the current value of I_γ is at its largest, and is non-zero for all other values. This representation allows for viscoelastic (fading memory) response on unloading.

The bulk stress, σ_B, in equation (8) was taken to be essentially time-independent, although there is coupling between distortion and dilatation as indicated in the exponential multiplier in equations (9) and (13).

The first attempt to represent the bulk stress took the form of a series

$$\frac{\sigma_{kk}}{3} = \sum_{i,\, j = 0}^{N} A_{ij}\, I_d^i\, I_\gamma^j \quad ; \; A_\infty = 0 \tag{14}$$

This equation adequately predicts the bulk stress as long as it does not vary greatly. However, when a hydrostatic pressure is superimposed, very poor results are obtained. In an attempt to overcome this difficulty, Farris modeled the compressibility of the gas voids caused by vacuole dilatation by treating them as spherical voids contained in an elastic medium. Assuming that (1) the voids themselves offer no resistance, (2) that all void dilatation is caused by distortion of the surrounding elastic material, (3) the void content at zero pressure may be represented as a power law in terms of the octahedral shear strain I_γ , and (4) that the bulk behavior varies linearly with hydrostatic pressure (P), the model yields:

$$I_d = C_1 P + C_2 I_\gamma^{\,n} e^{\left(\frac{-3P}{4G}\right)} \tag{15}$$

for the dilatation. The C_1, C_2 and n are constants and G is the shear modulus of the elastic matrix material.

4.2.3 R. Schapery's Nonlinear Stress-Strain Law

4.2.3.1 Original Model

The constitutive theory advanced in References 17 and 18 for viscoelastic materials with microcracking was taken by Dr. R. Schapery as the starting point for predicting the response of solid propellants under general loading conditions. The one-dimensional version of this law takes the following simple form:

$$\sigma = \frac{A_F}{\lambda}\sigma_\ell \tag{16}$$

where σ_ℓ is the linear viscoelastic stress for a thermorheologically simple material:

$$\sigma_\ell = \int_0^t E\,(\xi - \xi')\,\frac{d\epsilon_\sigma}{d\tau}\,d\tau \quad , \tag{17}$$

with $\epsilon_\sigma \equiv \epsilon - \alpha\,(T - T_o)$ = strain due to mechanically applied stress

$$\xi = \int_0^t dt'/A_T\left[T(t')\right]$$

$\xi' \equiv \xi\,(\tau)$

$E(\xi)$ = linear viscoelastic relaxation modulus

T_o = temperature at t = 0

$A_F = A_F\,(T)$ = temperature-dependent material function

$\lambda = \lambda\,(S_\ell)$: softening function in which the damage parameter:

$$S_\ell = \int_0^{\xi} \left(\frac{\sigma_\ell A_F}{f} \right)^q d\hat{\xi} \tag{18}$$

depends only on the strain and temperature histories, and:

$$f = \begin{cases} 1 & \text{for } 0 \leqslant \epsilon < \epsilon_1 \\ (\epsilon/\epsilon_1)^\beta & \text{for } \epsilon_1 \leqslant \epsilon < \epsilon_2 \\ (\epsilon_2/\epsilon_1)^\beta & \text{for } \epsilon \geqslant \epsilon_2 \end{cases}$$

for constant threshold strains ϵ_1 and ϵ_2, with $\beta>0$.

The function $F = F(\epsilon_\sigma)$ and the positive, constant exponent, q, originate with the equation for microcrack speed,

$$\frac{dA}{d\hat{\xi}} = M(K_I/f)^q \tag{19}$$

where M is a positive constant and:

$$d\hat{\xi} = dt/A_c \tag{20}$$

in which $A_c = A_c(T)$ is the shift-factor for microcrack growth rate.

The functional form of the softening function, $\lambda = \lambda(S_\ell)$, depends on the type of behavior that need be reproduced. The following special case was used:

$$\lambda = \left[1 + cS_\ell \right]^{p/q}$$

where c and p are positive constants. Note that when $S_\ell = 0$, or $c = 0$, a linear viscoelastic stress-strain equation is recovered from Equation (16).

Taking $A_F \equiv 1$, several sets of numerical values for the constitutive parameters corresponding to TP-H1011 were tried without success. This theory was also

used to predict the response of UTP-19,360 and UTP-3001. Having failed to perform better than Linear Viscoelasticity in many cases, it has undergone several changes since.

4.2.3.2 Current Model

The essential form of the modified uniaxial stress-strain relation is given by:

$$\sigma = f\,(\epsilon^{o}, \epsilon^{o}m, S) \tag{21}$$

where:

σ = engineering stress

ϵ^{o}_{r} = psuedo strain

$$\epsilon^{o}_{r} = \frac{1}{E_R} \int_{o}^{t} E\,(t - \tau)\frac{d\epsilon}{d\tau}d\tau \tag{22}$$

ϵ^{o}_{m} = maximum value of $|\epsilon^{o}|$ up to the current time

S = damage parameter

$$S = \left(\int_{o}^{t} \left|\epsilon^{o}\right|^{q} \, dt \right)^{1/q} \tag{23}$$

E_R = arbitrarily selected reference modulus,

E(t) = linear viscoelastic relaxation modulus,

$$= E_e + E_2\, t^{-n} \equiv E_2\,(E_\tau + t^{-n}), \tag{24}$$

$E_\tau = E_e/E_2$,

and q = positive constant.

The functional form of f in equation (21) depends on the material considered. Studies on solid propellant to date indicate it may be taken as follows for some solid propellants.

$$f = Y_1 \; Y_2 \; Y_3 \; P_{15} \; \text{sign} \; (\epsilon^{o}) \tag{25}$$

in which

$$\text{sign} \; (\epsilon^{o}) = \begin{cases} 1 & \text{if} \quad \epsilon^{o} > 0 \\ 0 & \text{if} \quad \epsilon^{o} = 0 \\ -1 & \text{if} \quad \epsilon^{o} < 0 \end{cases}$$

and P_{15} is used to normalize function Y_3 to unity, at a reference point. The Y_i's are the following functions of damage and pseudo strain:

$$Y_1 = Y_1 \; (S) = \begin{cases} 1 + A_1 S + A_2 S^2 + A_3 S^3 & \text{for } S \leq S_o \\ A_4 \; S^{A_5} & \text{for } S > S_o \end{cases} \tag{26}$$

$$Y_2 = A_2 \; S^{0.63 - Sx} \; (\epsilon_m^{o}) (0.463 - M_x - L_x) \; \left|\epsilon^{o}\right|^{L_x} \tag{27}$$

$$Y_3 = C_o + C_1 x + C_2 x^2 + C_3 x^3 + C_4 x^4 + C_5 x^5 \tag{28}$$

where:

$$x = x_r \left| \frac{\epsilon^{o}}{\epsilon_m^{o}} \right| \lambda \tag{29}$$

in which x_r is the only root of the equation:

$$\max(S_r) = Y_3 \; (x_r) \tag{30}$$

with max (S_r) representing the maximum value of S_r up to the current time, and:

$$S_r = \frac{S^{s_x} \left| \epsilon_m^o \right|^{M_x}}{P_{15}} \tag{31}$$

while λ is a factor that accounts for relatively small higher order effects possibly due to rehealing and particle interaction.

The constants entering the definitions of Y_1, Y_2, and Y_3 depend on the material. For UTP-19,360B they are:

$$\begin{aligned} S_o &= 42 \\ S_x &= 0.637 \\ M_x &= -0.387 \\ L_x &= 0.85 \end{aligned} \tag{32}$$

and the factor λ is given by:

$$\lambda = K_x \, C_{cm}^{-C_x} \tag{33}$$

The resulting form of equation (21) for UTP-19,360B is thus:

$$\sigma = P_{15} \, A_6 \, Y_1 \, Y_3 \left| \epsilon^o \right|^{L_x} \operatorname{sign} (\epsilon^o) \tag{34}$$

Clearly, if $L_x = 1$, equation (34) may be written as:

$$\sigma = A_F \int_0^t E \, (t - \tau) \, \frac{d \epsilon}{d \tau} \, d \tau \tag{35}$$

in which $a_F = a_F \, (\epsilon^o, \, \epsilon_m^o, \, S)$ plays the role of a softening function, reminiscent of the Mullins-Tobin approach.

4.2.3.3 Stress Predictions

The current version of the nonlinear model developed by R. Schapery may be used to predict the response of solid propellants with a rather remarkable degree of accuracy, as may be seen in Figures 87 to 94, which are sample cases of the isothermal tests considered in the program. The first two plots (Figures 87 and 88) correspond to the highest and lowest constant rate tests

(Text continued on page 216.)

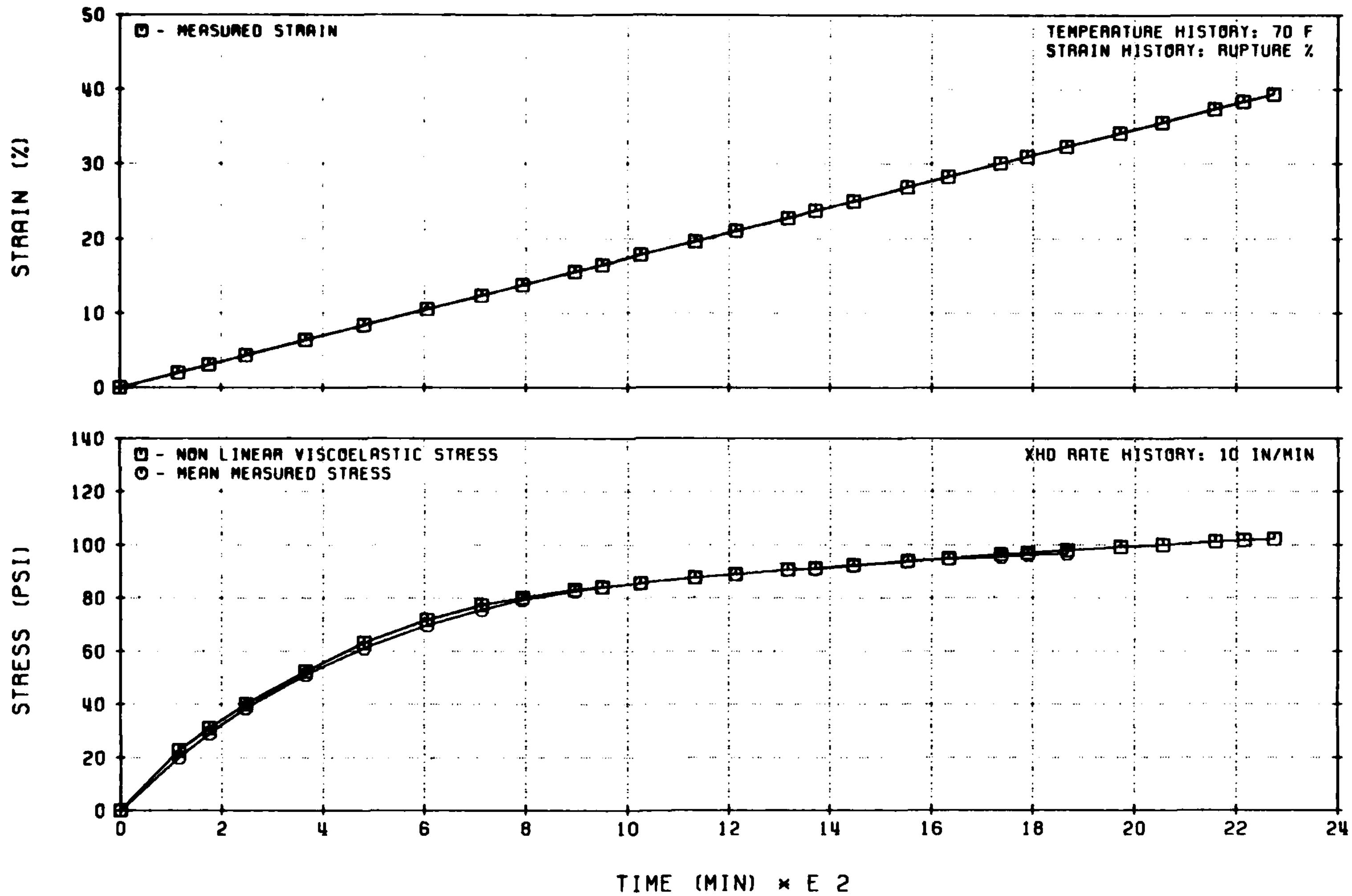


Figure 87. Dr. Schapery's Nonlinear Viscoelastic Stress Predictions for UTP-19,360B 400/1777 Constant Rate Test Data (Code No. 1)

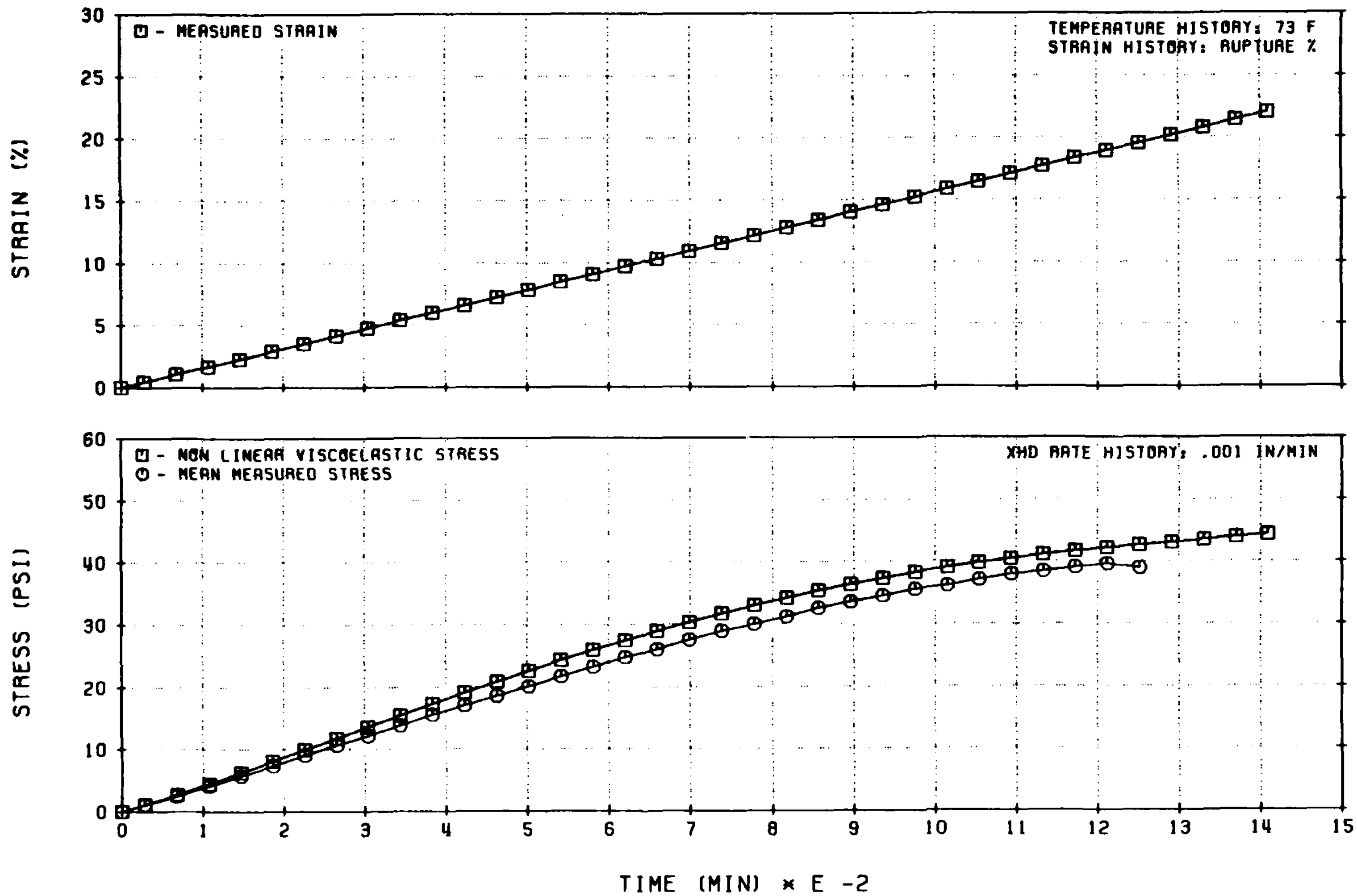


Figure 88. Dr. Schapery's Nonlinear Viscoelastic Stress Predictions for UTP-19,360B 400/1777 Constant Rate Test Data (Code No. 1)

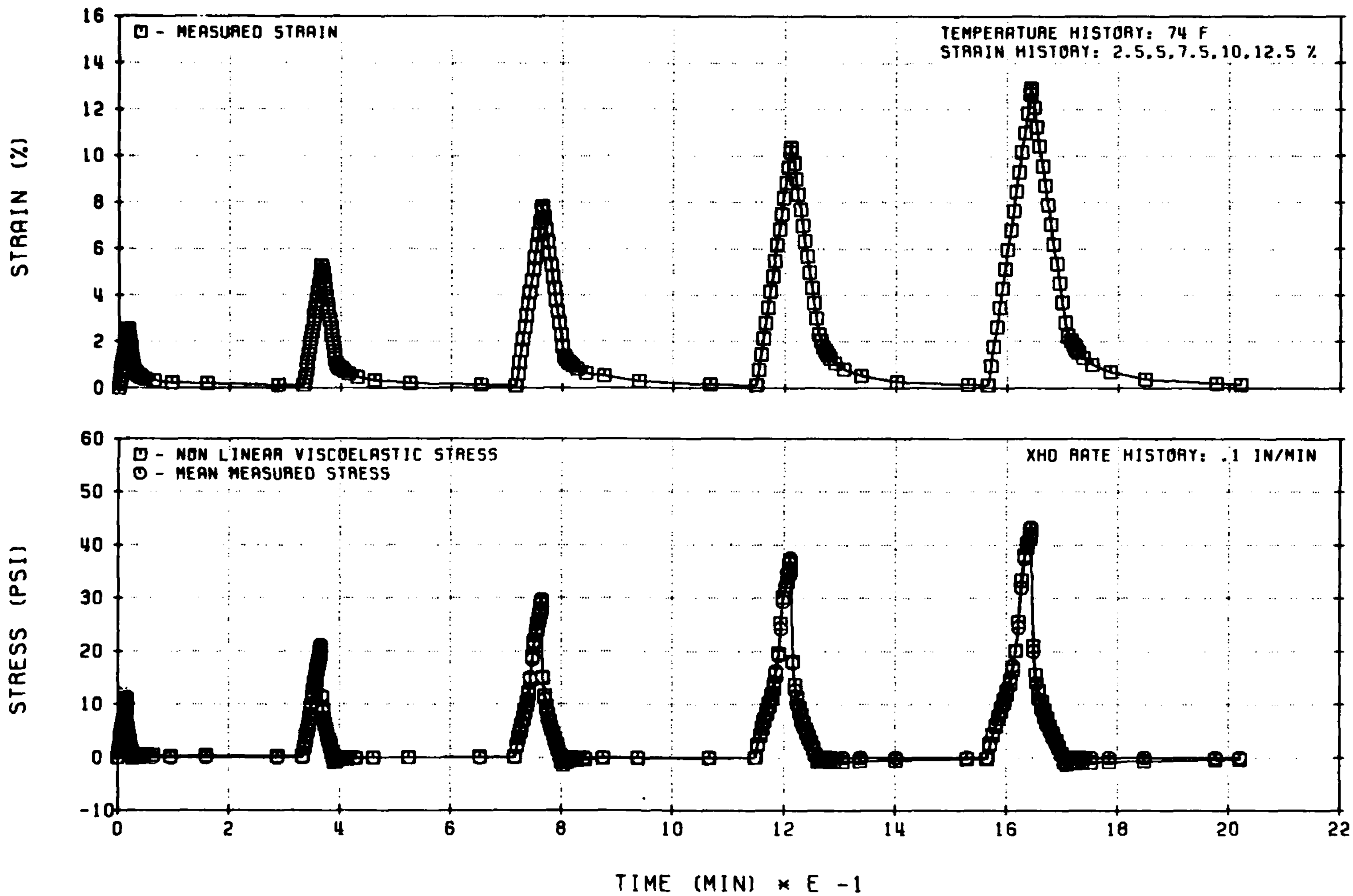


Figure 89. Dr. Schapery's Nonlinear Viscoelastic Stress Predictions for UTP-19,360B 400/1777 Multiple Loading Test History Data (Code No. 5)

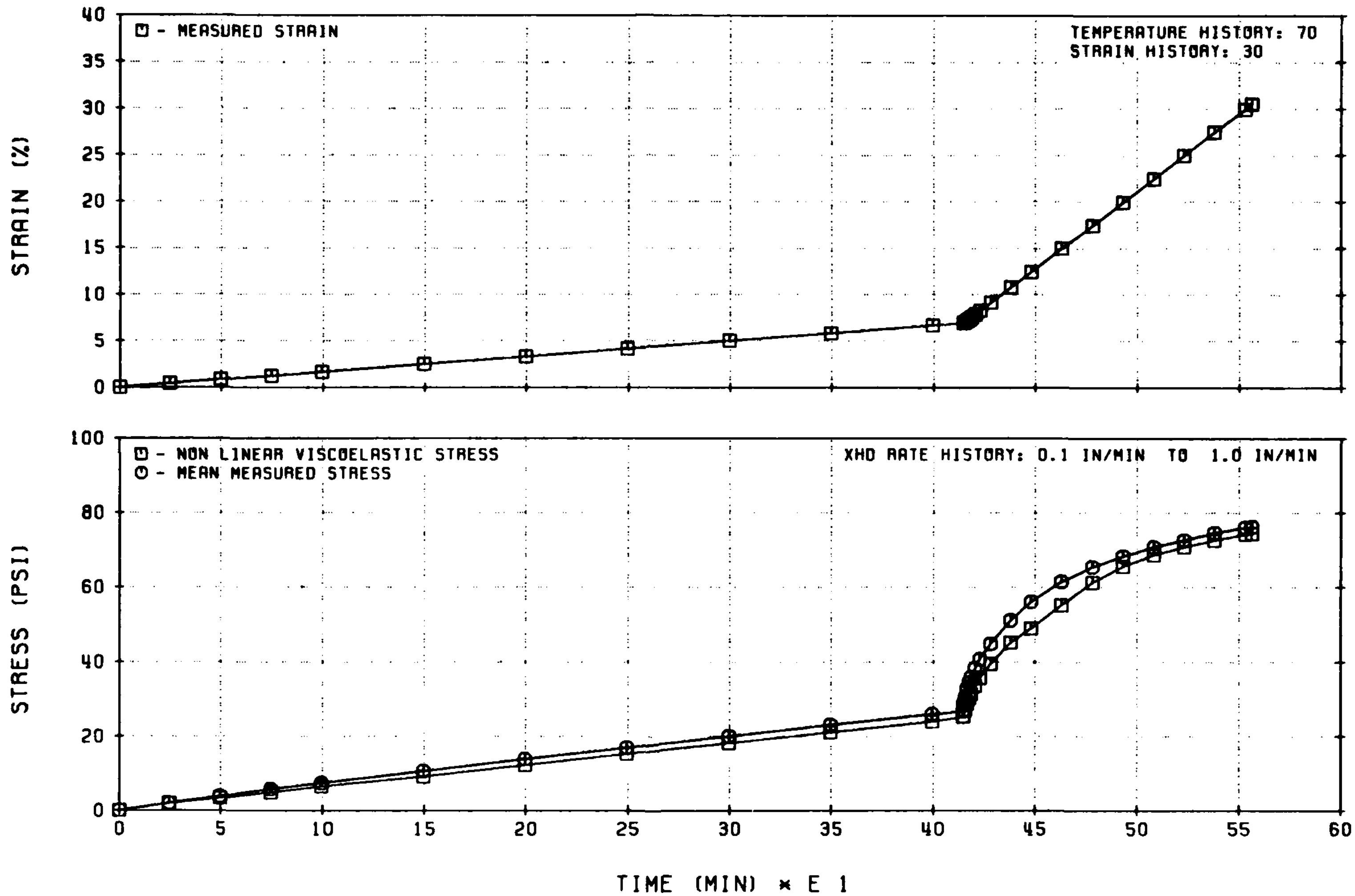


Figure 90. Dr. Schapery's Nonlinear Viscoelastic Stress Predictions for UTP-19,360B 400/1777 Two Rate Test Data (Code No. 3)

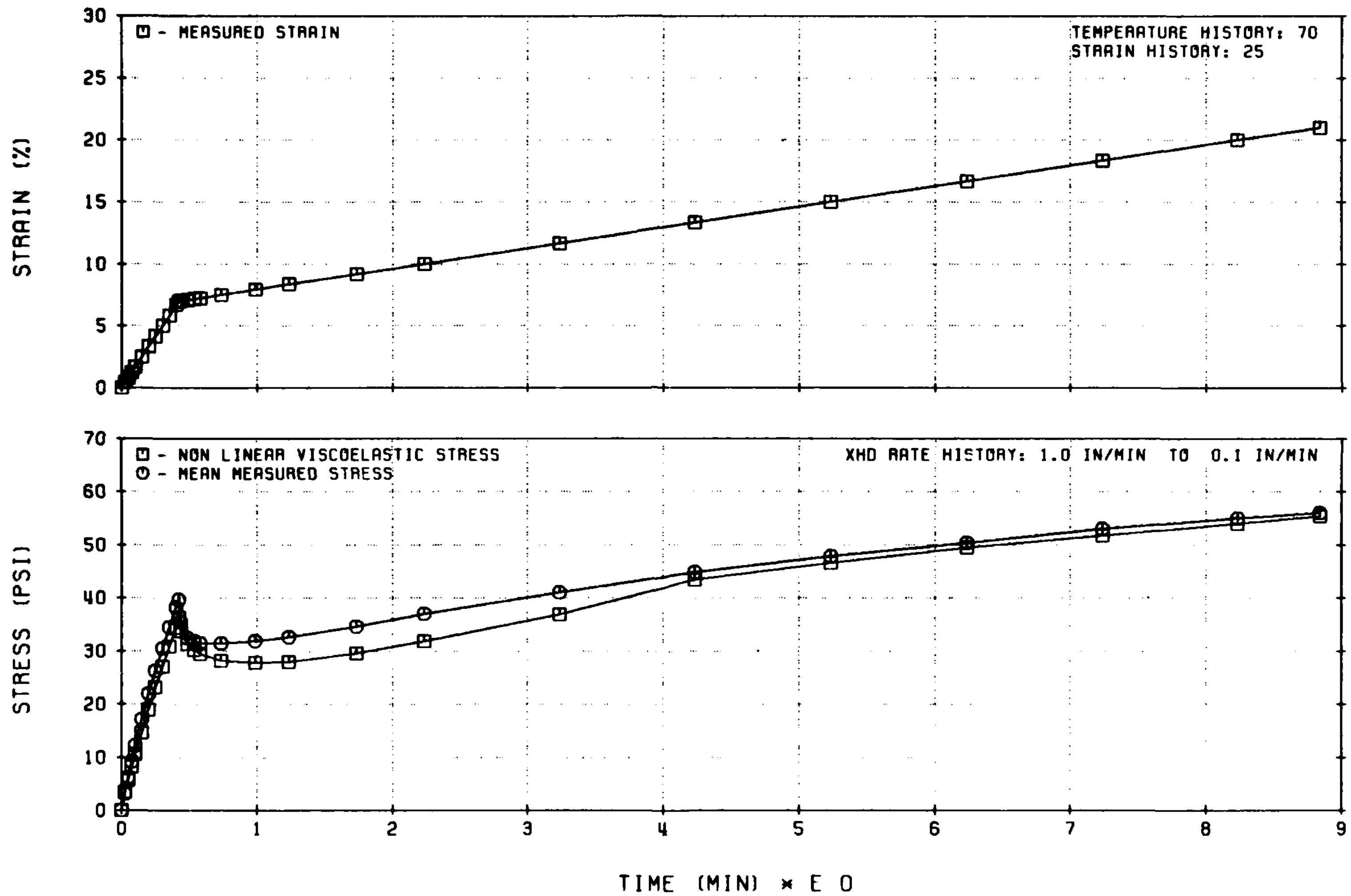


Figure 91. Dr. Schapery's Nonlinear Viscoelastic Stress Predictions for UTP-19,360B 400/1777 Two Rate Test Data (Code No. 3)

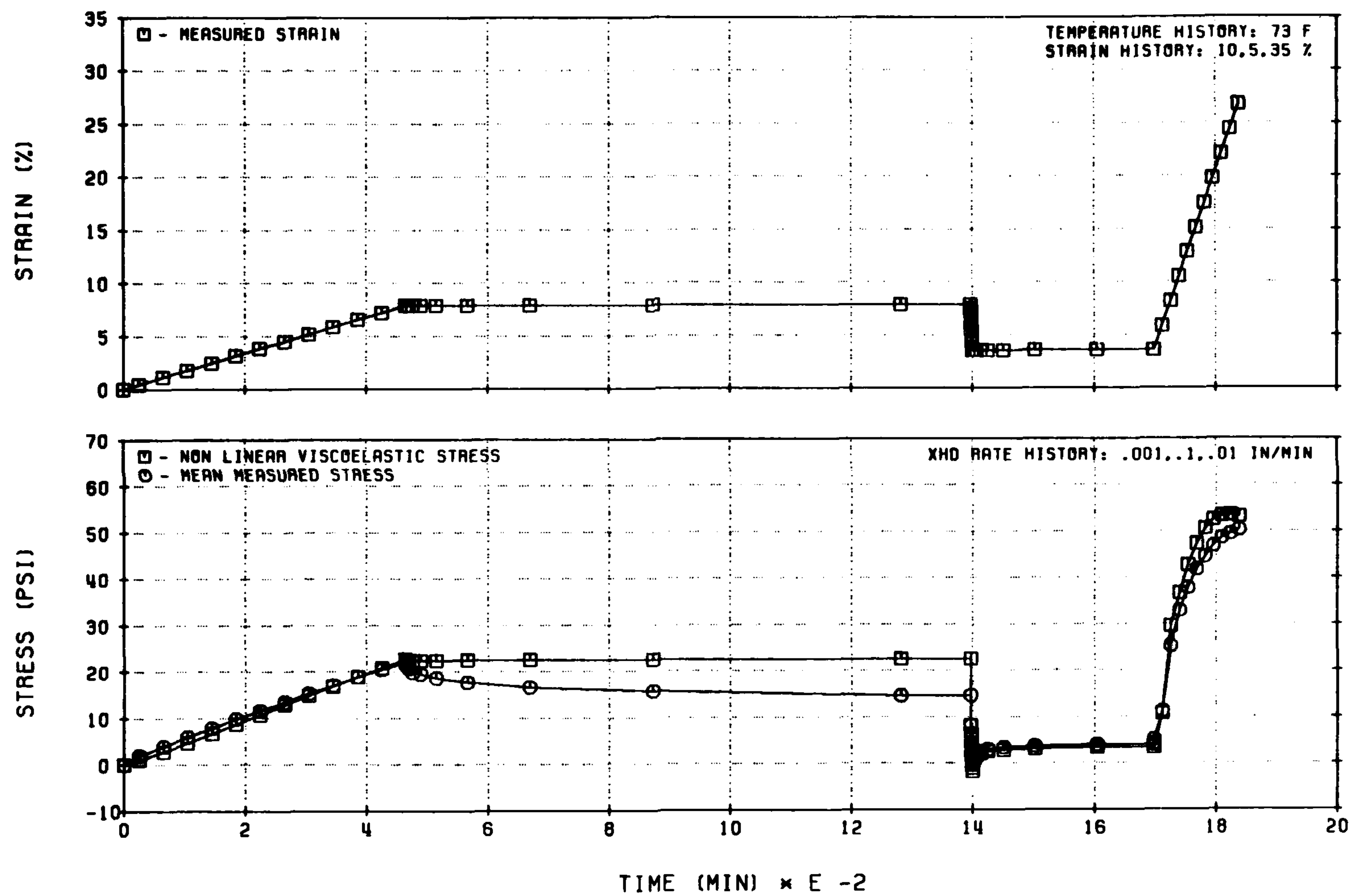


Figure 92. Dr. Schapery's Nonlinear Viscoelastic Stress Predictions for UTP-19,360B 400/1777 Similitude Test History Data (Code No. 12)

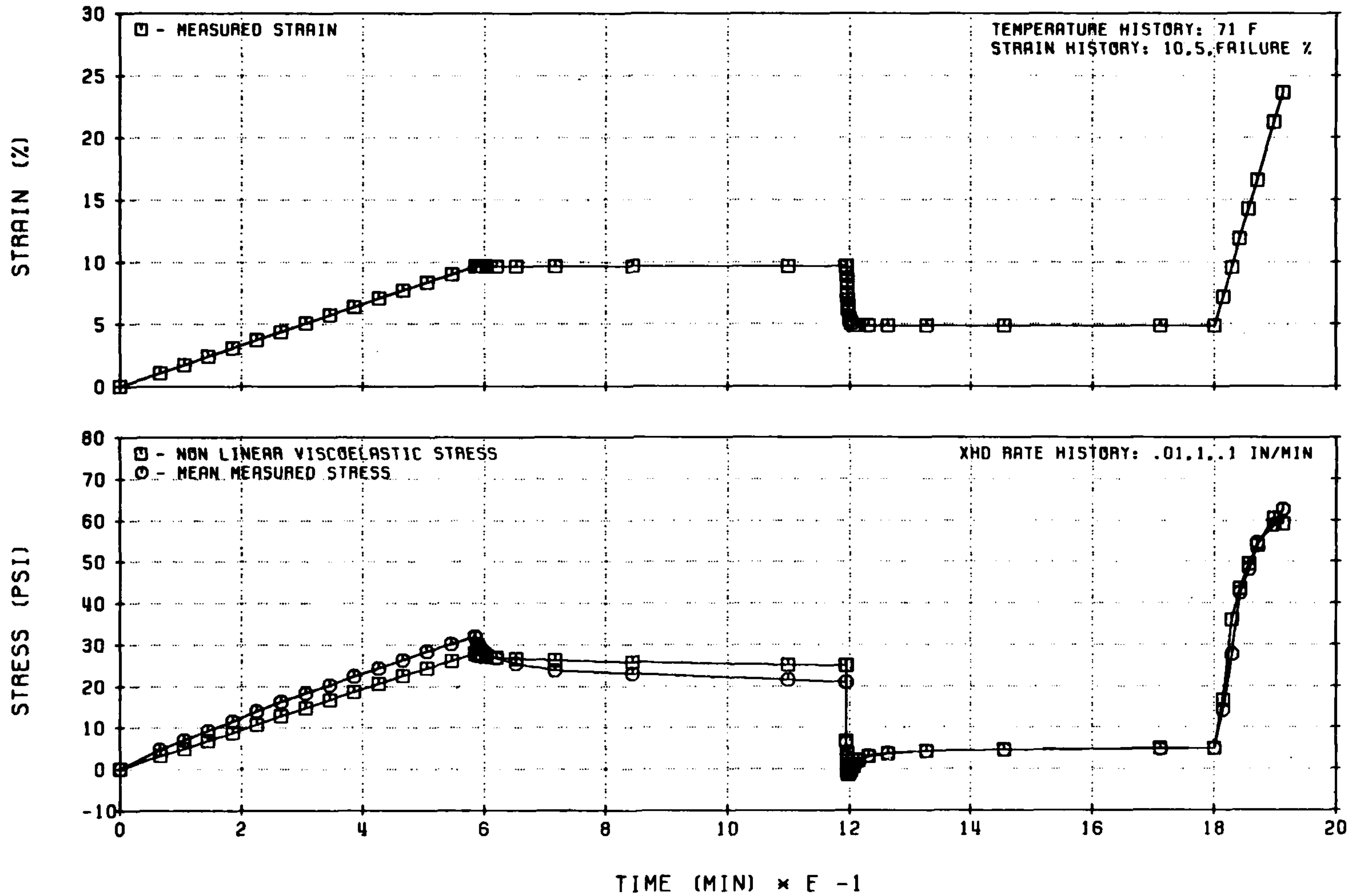


Figure 93. Dr. Schapery's Nonlinear Viscoelastic Stress Predictions for UTP-19,360B 400/1777 Similitude Test History (Code No. 12)

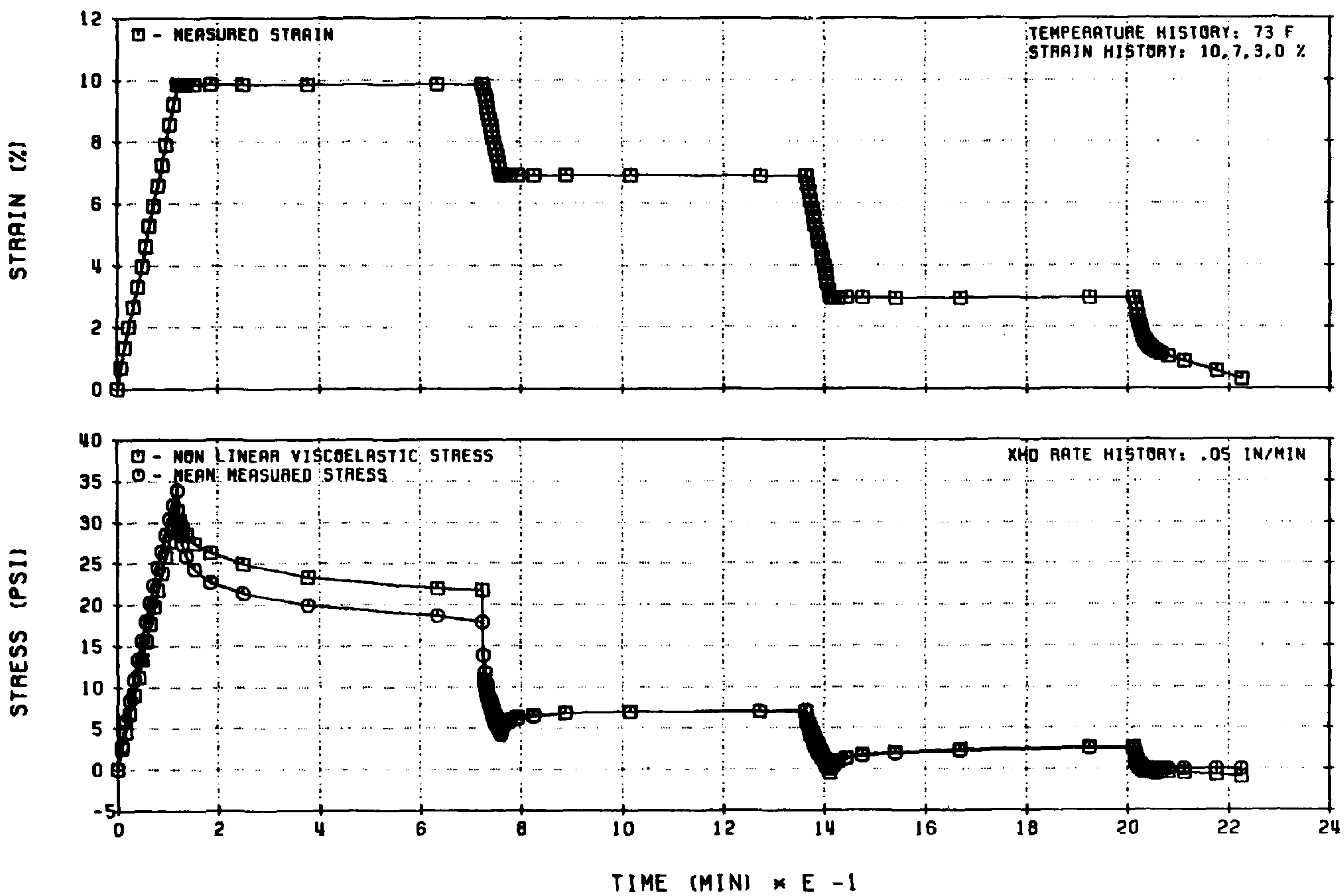


Figure 94. Dr. Schapery's Nonlinear Viscoelastic Stress Predictions for UTP-19,360B 400/1777 Three Step Relaxation Test History (Code No. 13)

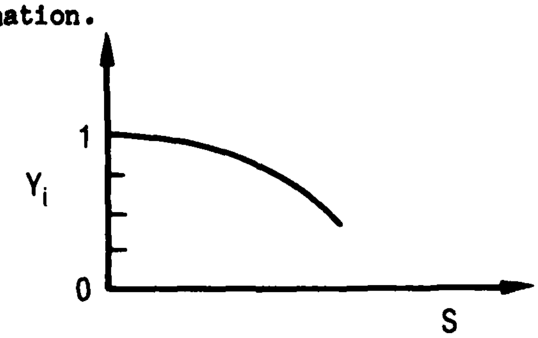
(Test No. 1) available in the data for which the difference between theory and test is greatest. Figure 89 shows the saw tooth test (Test No. 5) at constant rate with increasing strain peaks. Figures 90 and 91 pertain to the dual-rate tests (Test No. 3) Results for the short- and long-duration similitude tests (Test No. 12) are given in Figures 92 and 93, and Figure 94 includes a three-step relaxation test.

Finally, it is important to mention that a complete characterization of UTP-19,360B was also carried out using $L_x = 1$ (the value leading to equation (35)), and the ensuing response predictions were very close to those obtained with $L_x = 0.85$; only the low-to-high dual rate test of Figure 100 was predicted somewhat better with $L_x = 0.85$.

4.2.3.4 Material Characterization

In evaluating the material constants and property functions, the following observations may be valuable:

(1) Y_i appears to be a decreasing and concave down function of damage, as presented in the following figure, its variation being brought about by vacuole formation.

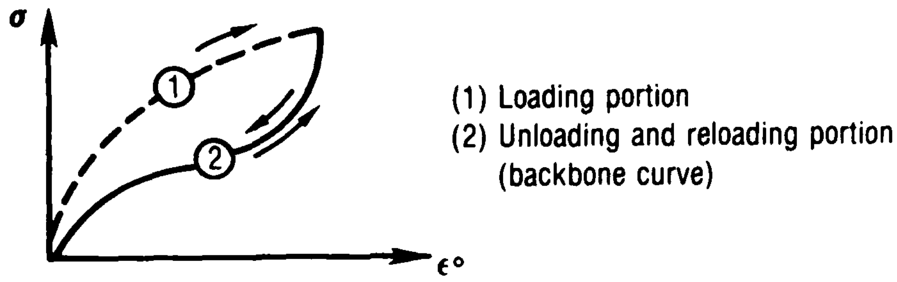


(2) The function S_r, which provides a certain measure of damage, increases as a direct result of a reduction in the number of polymer chains supporting the internal stresses; the larger S_r, the higher the stress on each chain.

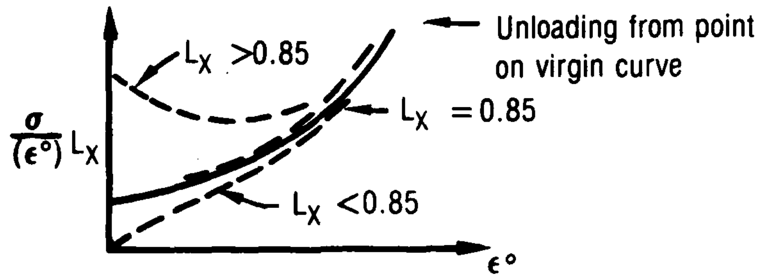
(3) For UTP-19,360B, the state of damage is essentially constant during unloading and reloading, and the shape of the so-called backbone curve resembles the stress-strain curve for rubber, which is of the form:

$$Y_3 \left| \epsilon^o \right|^{0.85} \qquad (36)$$

as shown in the sketch below, in which the steepness increased with increasing S_r.



(4) The selection of L_x can be made by plotting unloading data in the form suggested in the following diagram.



Noting that the quantity:

$$\frac{\sigma}{(\epsilon^o)^{L_x}}$$

resembles a secant modulus, and that for most tests of UTP-19,360B $L_x = 0.85$ produced a finite limiting value as ϵ^o approached zero, it is suggested that L_x be found in this fashion for other propellants.

(5) For constant-rate tests, one has:

$$\epsilon^o = \epsilon^o_m$$
$$\lambda = 1$$

and thus, from equation (29):

$$X = X_r$$

Also:

$$S_r = \max (S_r)$$

from which:

$$Y_3 = S_r$$

Equation (34) then reduces to:

$$\sigma = 1.861\ Y_1\ S^{0.637}\ (\epsilon_m^o)^{0.463} \tag{37}$$

with $Y_1 = Y_1\ (S)$ given by equation (26).
For very small damage:

$$Y_1\ (S) = 1$$

so that equation (36) becomes:

$$\sigma \cong 1.861\ S^{0.637}\ (\epsilon_m^o)^{0.463} \tag{38}$$

in which the stress increases with damage, probably because of molecular chain stiffening due to an increase in stress per chain.

With the foregoing observations in mind, determining the material properties can be accomplished as follows:

(1) The exponent, n, appearing in the relaxation function, is obtained from relaxation-modulus data.
(2) The normalized coefficient, E_r, entering the relaxation modulus, is determined to make unloading curve 2 in the figure above pass through the origin.

(3) The exponent, q, present in the definition of the damage parameter, is evaluated using equation (37) and two constant-rate tests at small values of damage.

(4) The function Y_1 is obtained by curve-fitting equation (36) to constant-rate tests over all strains out to failure.

(5) Experience to date indicates that the function Y_2 is independent of S and ϵ_m, and therefore equation (30) may be used instead of the more general form of equation (37).

(6) The backbone curve Y_3 is determined using unloading and reloading data like those available in a cyclic test whose first peak strain is the largest.

(7) Finally the correction factor, λ, can be ascertained from a relaxation test at a large strain level.

4.2.3.5 Multiaxial Generalization

A micromechanics model has been developed which predicts the form of equation (30), and it is presently being used to develop a multiaxial form of the theory.

4.2.4 M. Gurtin's Theories for Nonlinear Viscoelastic Materials

Four essentially different approaches have been followed by M. Gurtin in trying to predict the response of solid propellants that exhibit damage. The stress-softening theory appears to be the most accurate of the four laws as will be pointed out.

4.2.4.1 Original Model

The one-dimensional stress-strain law for materials undergoing internal damage was based on the hypothesis that the state of damage at any time is completely characterized by the maximum strain, ϵ_m, that the material has experienced.

$$\epsilon_m(t) = \max_{0 \leq s \leq t} \epsilon(s) \tag{39}$$

The stress, σ, is given by a constitutive equation of the form:

$$\sigma(t) = g\left[\epsilon(t), \epsilon_m(t)\right] \tag{40}$$

and it depends only on the current values of strain and damage. Such an equation is, of course, rate-independent.

In this theory, if the maximum strain occurs at the present time, then:

$$\epsilon_m(t) = \epsilon(t), \tag{41}$$

and equation (39) reduces to:

$$\sigma = G(\epsilon_m) = g(\epsilon_m, \epsilon_m) \tag{42}$$

The stress-strain curve:

$$\sigma = G(\epsilon_m) \tag{43}$$

is called the virgin curve and is traced out in an experiment with monotonically increasing strain.

Using the virgin curve, equation (39) may be rewritten in the form:

$$\sigma = F(\xi, \epsilon_m)\, G(\epsilon_m) \tag{44}$$

with:

$$\xi = \frac{\epsilon}{\epsilon_m} \tag{45}$$

the relative strain, and:

$$F(\xi, \epsilon_m) = \frac{g(\epsilon_m, \epsilon_m)}{G(\epsilon_m)} \tag{46}$$

The function $F(\xi, \epsilon_m)$ is called the damage curve at the damage level ϵ_m, and is such that:

$$F(1, \epsilon_m) = 1 \tag{47}$$

In some situations of interest $F(\xi, \epsilon_m)$ is independent of ϵ_m:

$$F(\xi, \epsilon_m) = F(\xi) \tag{48}$$

when this is so, $F(\xi)$ is referred to as the master damage curve, and equation (43) reduces to:

$$\sigma = F(\xi)G(\epsilon_m) \tag{49}$$

As pointed out previously, this is a rate-independent theory, and as such, cannot be used for loading rates that differ much from that used to determine the damage function. This situation was remedied by changing the stress-strain law to the one described next.

4.2.4.2 Nonlinear Model Based on Stress Softening

To develop a simple theory of stress softening which allows for rate effects and which returns to Mullins' original idea of using the past stress maximum as the damage parameter, two fundamental ingredients are considered. The first is the virgin stress, S, which represents the stress the material would experience in the absence of softening. This stress is assumed governed by a constitutive equation of the type encountered in linear viscoelasticity. The second ingredient is a damage function, F, which gives the true stress, σ, when the virgin stress, S, and its past maximum S_m, are known.

The one-dimensional form of the constitutive law for a classical linear viscoelastic material is given by:

$$\sigma(t) = \int_{-\infty}^{t} G(t-\tau)\,\dot{\epsilon}(\tau)\,d\tau \tag{50}$$

in which $\sigma(t)$ is the stress; $\epsilon(t)$, the strain; and $G(t)$, the relaxation function. It is further assumed that $\epsilon(t)=0$, prior to $t = 0$.

The generalization of equation (50) is begun by defining the quantity:

$$S(t) = \int_{-\tau}^{t} G(t - \tau)\, \dot{\epsilon}(\tau)\, d\tau \tag{51}$$

which is called the virgin stress and which represents the stress that would be present in the absence of softening. It is assumed that the extent of softening is governed by a constitutive equation giving the true stress, $\sigma(t)$, when $S(t)$ and its past maximum are known.

$$S_m(t) = \max_{0 \leq \tau \leq st} S(\tau) \tag{52}$$

Without loss of generality, this constitutive equation is written in the form:

$$\sigma = S_m\, F\left(\frac{S}{S_m}, S_m\right) \tag{53}$$

and it is assumed that the damage function, F, satisfies the following conditions:

$$\begin{aligned} &F(1, S_m) = 1 \\ &F(x, S_m) < x \quad \text{for } x < 1 \end{aligned} \tag{54}$$

These restrictions imply that:

$$\sigma(t) \leq S(t), \tag{55}$$

also that:

$$\sigma_m(t) = S_m(t), \tag{56}$$

and, that the following conditions are equivalent:

$$\begin{aligned} &\text{i)} \quad \sigma(t) = S(t) \\ &\text{ii)} \quad S(t) = S_m(t) \\ &\text{iii)} \quad \sigma(t) = \sigma_m(t) \end{aligned} \tag{57}$$

where σ_m is the past stress maximum, defined analogically to S_m. The inequality equation (54) asserts that the material actually softens, while equation (56) indicates that this softening occurs when and only when $S(t) < S_m(t)$ (or equivalently $\sigma(t)<\sigma_m(t)$). The results of equation (55) and (56) show that one may equally well use the true stress, $\sigma(t)$, as the damage parameter.

Equation (54) and the fact that the first relation of equation (57) implies the third are direct consequences of the hypotheses laid down in equation (58). To verify equation (55), note that if the maximum of S on the interval $0 \leq \tau \leq t$, occurs at $\tau = \xi$, then:

$$S_m(t) = S(\xi) \tag{58}$$

thus using equation (57) in (52), and recalling that equation (53):

$$\sigma(\xi) = S(\xi)\ F(1,\ S_m) \equiv S(\xi) \tag{59}$$

which, by virtue of (57) and the definition of S_m, implies that:

$$\sigma(\xi) = S(\xi) = S_m(t) \geq S(\lambda) \geq \sigma(\lambda); \quad 0 \leq \lambda \leq t\ S \tag{60}$$

proving equations (54) and (55) and the first two equations of equation (57). To establish the third relation in equation (57), note that if:

$$S_m(t) = S(t)$$

which implies that:

$$S_m(t) = \sigma(t)$$

because of equation (58); then, since

$$S_m = \sigma_m \tag{61}$$

one would have that:

$$\sigma_m(t) = \sigma(t).$$

Conversely, if

$$\sigma(t) = \sigma_m(t),$$

then:

$$S(t) \geq \sigma(t) = \sigma_m(t) = S_m(t)$$

so that:

$$S(t) = S_m(t).$$

Returning to the constitutive equation (52), it is interesting to consider the special case in which the damage function depends only on S/S_m:

$$F\left(\frac{S}{S_m}, S_m\right) \equiv F\left(\frac{S}{S_m}\right); \tag{62}$$

which is a master damage curve of the type considered in the rate-independent model discussed previously.

When the virgin stress obeys an elastic stress-strain relation:

$$S = E\epsilon \tag{63}$$

then:

$$S_m = E\epsilon_m \tag{64}$$

in which ϵ_m is the past strain-maximum, and equation (52) yields:

$$\sigma = E\epsilon_m \, F\left(\frac{\epsilon}{\epsilon_m}, \, E\epsilon_m\right) \tag{65}$$

so that, defining:

$$F^* \left(\frac{\epsilon}{\epsilon_m}, \, \epsilon_m\right) \equiv F\left(\frac{\epsilon}{\epsilon_m}, \, E\epsilon_m\right) \tag{66}$$

leads to the starting assumption of Gurtin and Francis (Reference 26):

$$\sigma = F^*\left(\frac{\epsilon}{\epsilon_m}, \, \epsilon_m\right) E\epsilon_m \tag{67}$$

presented earlier as the rate-independent model.

Although implicit in equation (52) is the assumption that the functional form of F would be the same for unloading conditions as for reloading, it was found experimentally that a different damage function is needed for each of these processes. Actually, there is more than one way of obtaining the same damage function. For TP-H1011, for instance, the following procedure was employed.

Considering the strain history shown in Figure 95, on the loading portion we have:

$$S(t) = \dot{\epsilon} \int_0^t G(\tau) \, d\tau \qquad \text{for } t < T \tag{68}$$

hence, S(t) increases monotonically and, by equation (55):

$$Sm(t) = S(t) = \sigma(t) \tag{69}$$

and, upon unloading, the past maximum of S is the true stress:

$$\sigma_m = \sigma(T), \qquad T < t < 2T \tag{70}$$

Further, by equation (50):

$$S(t) = |\dot{\epsilon}| \left\{ \int_0^T G(t - \tau)\, d\tau - \int_T^t G(t - \tau)\, d\tau \right\} \tag{71}$$

or, equivalently:

$$S(T + t) = G(t) - \sigma(t) \tag{72}$$

with:

$$G(t) \equiv |\dot{\epsilon}| \int_t^{t+T} G(\tau) d\tau \tag{73}$$

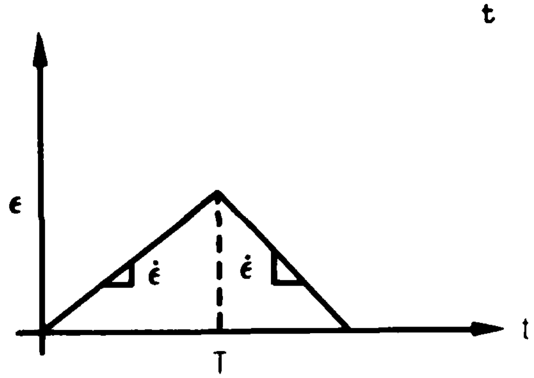


Figure 95. Strain History Used To Characterize the Damage Function

Letting $\sigma_1(t)$ and $\sigma_2(t)$ denote the true stress during loading and unloading, respectively, with t in $\sigma_2(t)$ measured from the time T at which unloading begins, equations (52) and (67) yield the simple formula:

$$\frac{\sigma_2(t)}{\sigma_m} = F\left[\frac{G(t) - \sigma_1(t)}{\sigma_m}, \sigma_m\right] \tag{74}$$

Thus, summarizing, the stress-softening approach to damage is described through the following constitutive equation:

$$\sigma(t) = S_m F\left(\frac{S}{S_m}, S_m\right) \tag{75}$$

where

$$S(t) = \int_0^t G(t - \tau) \frac{d\epsilon}{d\tau}(\tau)\, d\tau$$

and in which the damage function, F, may be determined from saw-tooth tests with increasing peak strains and with sufficiently long rest periods between cycles. For conditions of reloading, F is given by:

$$\frac{\sigma_2}{\sigma_m} = F\left[\frac{\sigma_1(t)}{\sigma_m}, \sigma_m\right] \tag{76}$$

while for unloading the following form is employed:

$$\frac{\sigma_2}{\sigma_m} = F\left[\frac{G(t) - \sigma_1(t)}{\sigma_m}, \sigma_m\right] \tag{77}$$

Typical curves for unloading and reloading damage functions of TP-H1011 are included as Figure 96 and 97, respectively.

Finally, we point out that the use of this approach to predict the response of TP-H1011 yielded results that were far more accurate than those obtained with any of the other theories in their original form.

4.2.4.3 Nonlinear Models Based on Maximum Strain.

A series of constitutive relations based on the past maximum strain have been proposed by M. Gurtin. The precursor of these relations took the form:

$$\sigma(t) = \int_0^t G(t - \tau) \frac{de}{d\tau}(\tau)\, d\tau \tag{78}$$

where G represents the relaxation modulus, and the function e was expressed as a product of the reduced damage function, F, and the virgin-response function, g, in the following way:

$$e = F\left(\frac{\epsilon}{\epsilon_m}, \epsilon_m\right) g\,(\epsilon_m) \tag{79}$$

with:

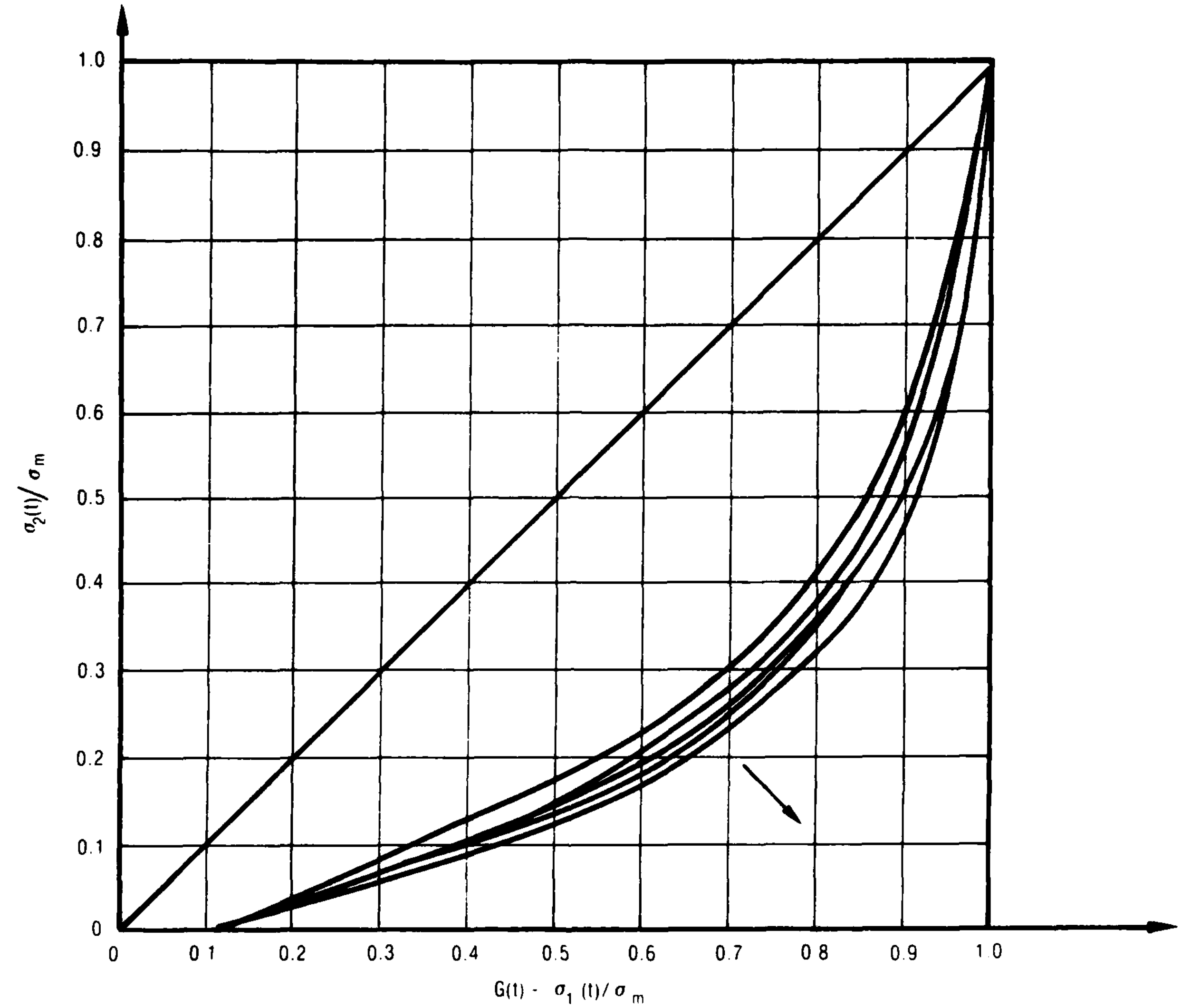


Figure 96. Damage Function for Unloading (TP-H1011)

28896

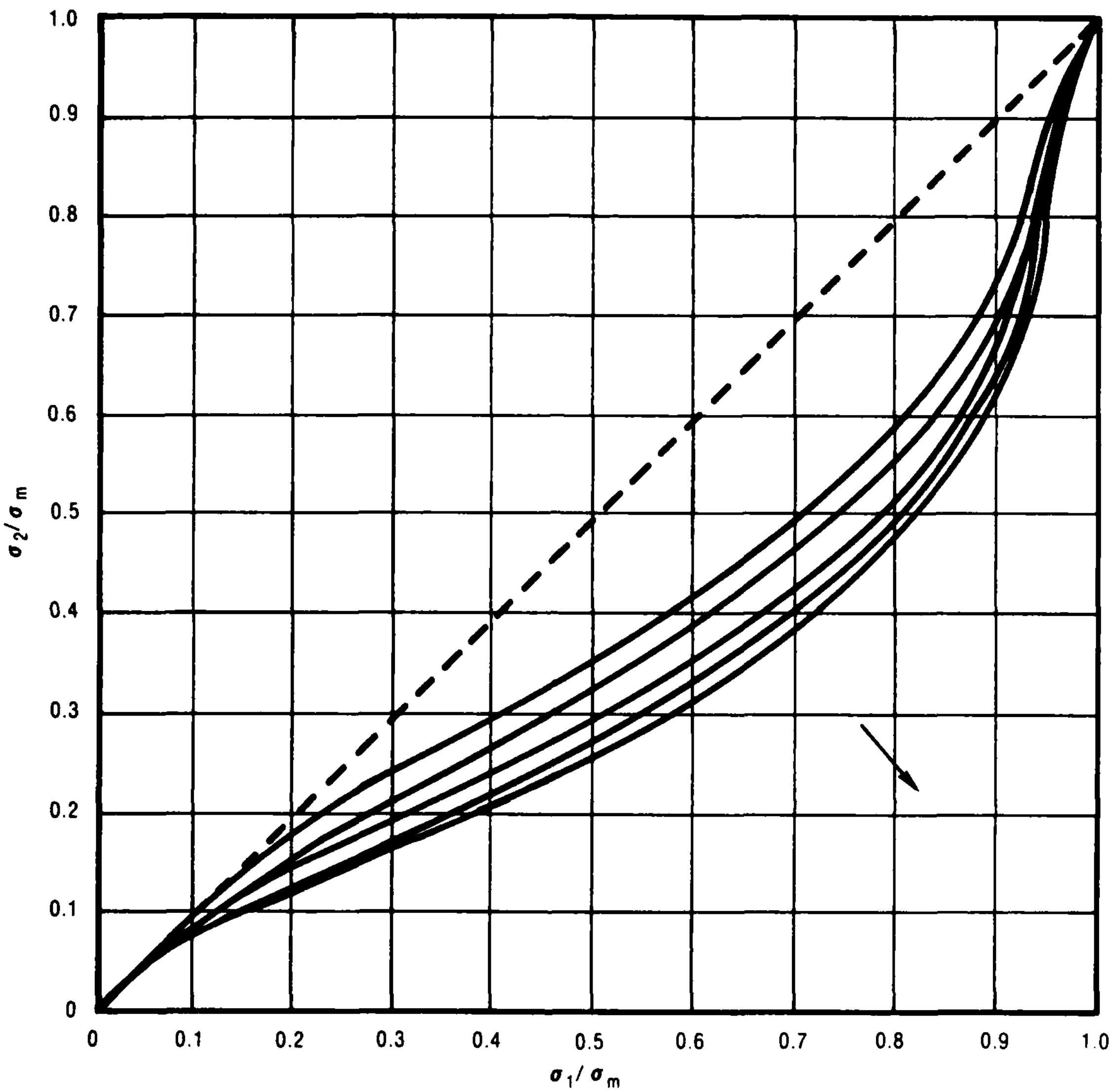


Figure 97. Damage Function for Reloading (TP-H1011)

28892

$$F(1,\epsilon_m) = 1 \tag{80}$$

and

$$\epsilon_m = \max_{0 \leq \tau \leq t} \epsilon(\tau) \tag{81}$$

so that, during virgin response, since:

$$\epsilon = \epsilon_m \tag{82}$$

one had:

$$\sigma(t) = \int_0^t G(t - \tau) \frac{dg(\epsilon)}{d\epsilon} \frac{d\epsilon(\tau)}{d\tau} d\tau \tag{83}$$

and, by taking:

$$g(\epsilon) = \sum_{k=1}^{k=K} A_k \epsilon^k \tag{84}$$

the best values for the a_k's could be determined using least squares and the data of all constant-rate tests.

To characterize the reduced damage function, F, involved the determination of a creep function, J, solution of:

$$\int_0^t G(t - \tau) \frac{dJ(\tau)}{d\tau} d\tau = 1 \tag{85}$$

and, such that:

$$e(t) = \int_0^t J(t - \tau) \frac{d\sigma(\tau)}{d\tau} d\tau \tag{86}$$

Thus, taking the reduced damage function, F, in the form:

$$F\,(x,\ y) = F_1\,(x)\ F_2\,(x,y) \tag{87}$$

with

$$F_1\,(x) = x^M + \sum_{m=1}^{M-1} d_m\,(x^m - x^M) \tag{88}$$

$$F_2\,(x,y) = 1 + \sum_{p=1}^{P} b_p\ y^p \left[x - x^Q + \sum_{q-2}^{Q-1} C_q\,(\,q - \ Q)\right] \tag{89}$$

and equating equations (71) and (75), the coefficients entering F were to be determined using least squares and all the saw-tooth data with increasing strain peaks.

When this constitutive law was applied to UTP-19,360B data, it was deemed necessary to change the form of the function e, because of the large errors observed in the predicted response.

The last of a sequence of modifications yielded the following stress-strain law:

$$\sigma(t) = \int_{o}^{t} G(t - \tau) \left\{ K\left(\epsilon_m, \dot{\epsilon}_m\ \frac{d}{d\tau}\left[F\left(\frac{\epsilon}{\epsilon_m},\ \epsilon_m\right)\epsilon_m\right]\right\} d\tau \tag{90}$$

where, as before, G was the relaxation modulus, and:

$$F\,(1, \epsilon_m) = 1 \tag{91}$$

with:

$$\epsilon_m = \max_{0 < \tau < t} \epsilon(\tau) \tag{92}$$

In the present case, the virgin response was given by:

$$\sigma(t) = \int_{o}^{t} G(t - \tau)\ K\ (\epsilon_m, \dot{\epsilon}_m)\ \frac{d\epsilon_m}{d\tau}\ d\tau \tag{93}$$

while, the damage response, for which ϵ_m remains constant, took the form:

$$\sigma(t) = K\ (\epsilon_m, 0) \int_{o}^{t} G(t - \tau) \frac{\partial F}{\partial x}\ (x,y)\ d\tau \tag{94}$$

in which:

$$K(\epsilon, \dot{\epsilon}) = 1 + A_1\ (\epsilon - \epsilon_o) + A_2\ (\epsilon - \epsilon_o)^2 + A_3\ (\epsilon - \epsilon_o)^3 + + \dot{\epsilon}\ (B_1 \epsilon + B_2 \epsilon^2 + B_3 \epsilon^3) \tag{95}$$

$$F(x,y) = \alpha(x) \left[1 + (D_5\ y + D_7\ y^2) \left\{ x - x^3 + D_6\ (x^2 - x^3) \right\} \right] \tag{96}$$

$$\alpha(x) \equiv x^5 + \sum_{m=1}^{4} D_m\ (x^m - x^5) \tag{97}$$

with:

$$x \equiv \epsilon / \epsilon_m \tag{98}$$

and:

$$y \equiv \epsilon_m \tag{99}$$

A set of stress predictions obtained for UTP-19,360B, with the resulting version of the theory, is included in Figures 98 through 104. Figure 98 is for the high-to-low dual rate test, Figures 99 through 101 are segments of the long-duration similitude test, and Figure 102 through 104 are segments of the three step relaxation test.

Since the dependence of the function K on the strain rate was felt to be artificial, the treatment of damage was revised in the manner explained next.

4.2.4.4 Current Model

The latest version of M. Gurtin's nonlinear stress-strain law is based on a strain-dependent relaxation function and has the form:

$$\sigma(t) = \int_{0}^{t} G\left[\epsilon(\tau), \tau\right]\dot{\epsilon}(t - \tau)\, d\tau \tag{100}$$

where:

$$G(\epsilon, t) = G_r(t) + G_c(\epsilon, t) \tag{101}$$

G = relaxation modulus

G_c = correction modulus, defined as:

$$G_c(\epsilon, t) = \sum_{n=1}^{N} A_n(\epsilon)\,(e)^{-t/\tau_n} \tag{102}$$

$$A_n(\epsilon) = \sum_{p=1}^{P} A_{np}\,\epsilon^{p} \tag{103}$$

For this material, the virgin curve ($\epsilon = \epsilon_m = \epsilon$) is:

$$\sigma = \sigma_r + \sigma_c \tag{104}$$

with σ_r, the linear viscoelastic stress:

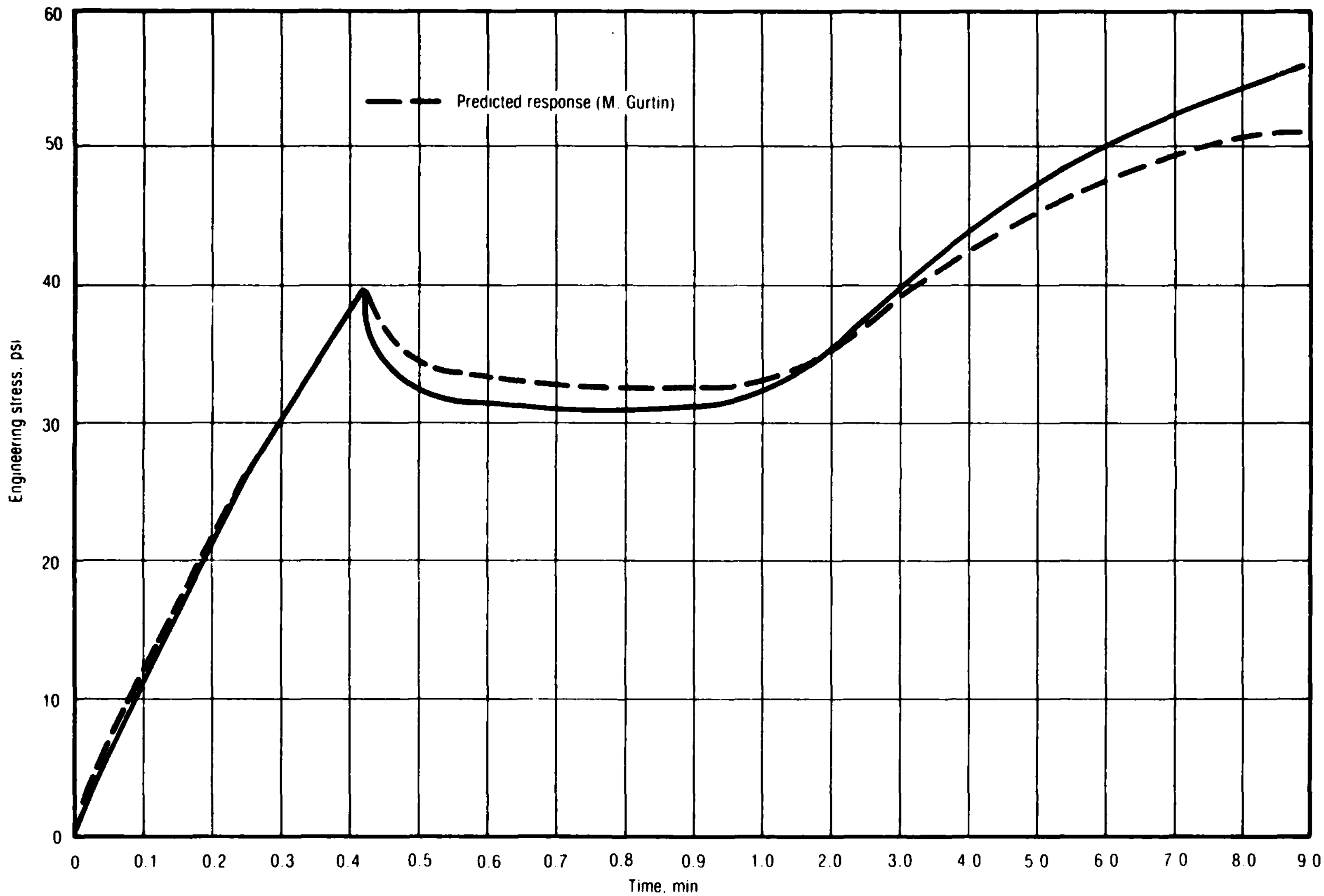


Figure 98. Two-Rate Loading (1 in./min to 0.1 in./min) of UTP-19,360B-400/1777

28006

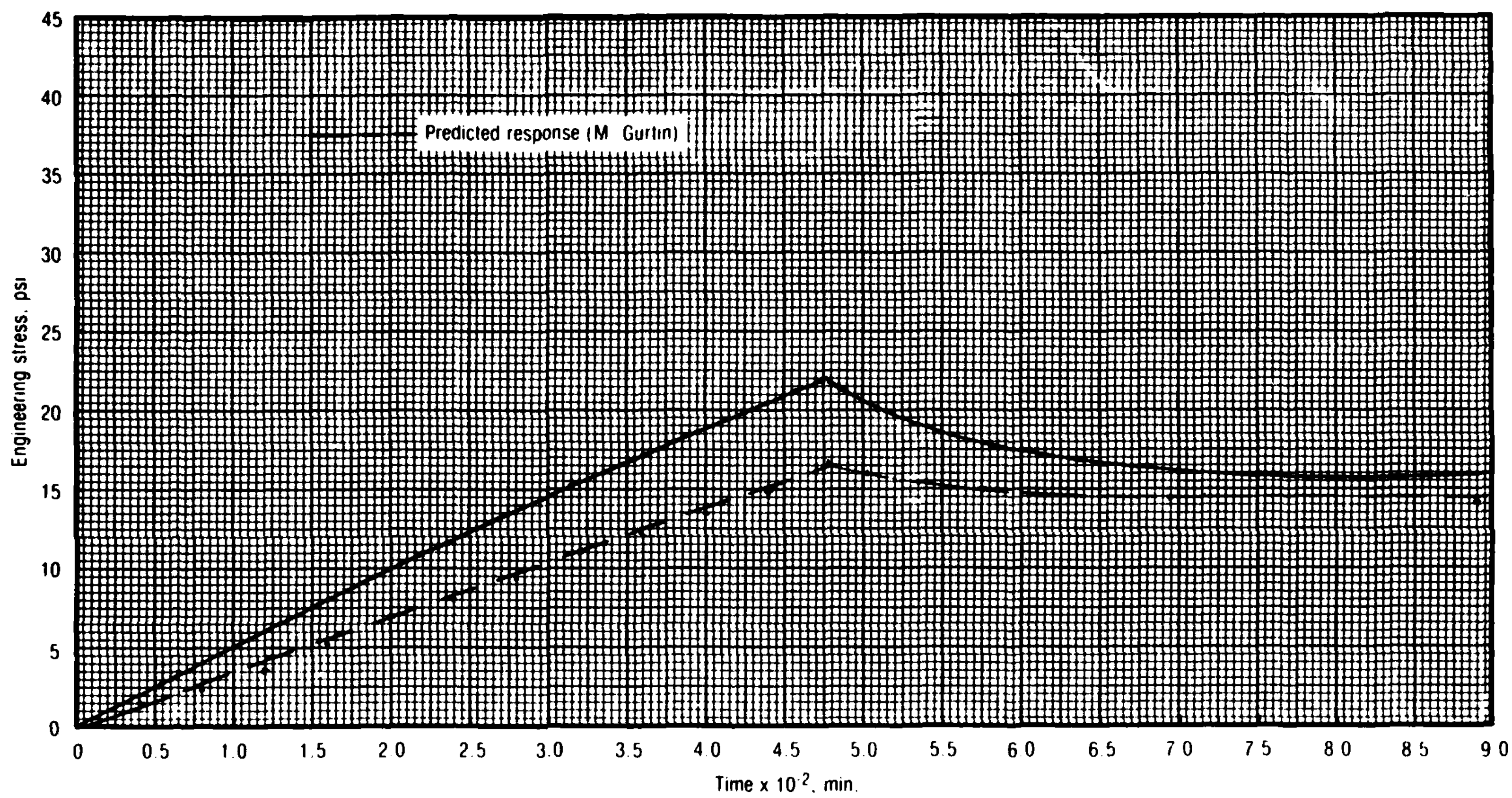


Figure 99. Relaxation-Unload-Reload of 6-in. Bar of UTP-19,360B-400/1777

28847

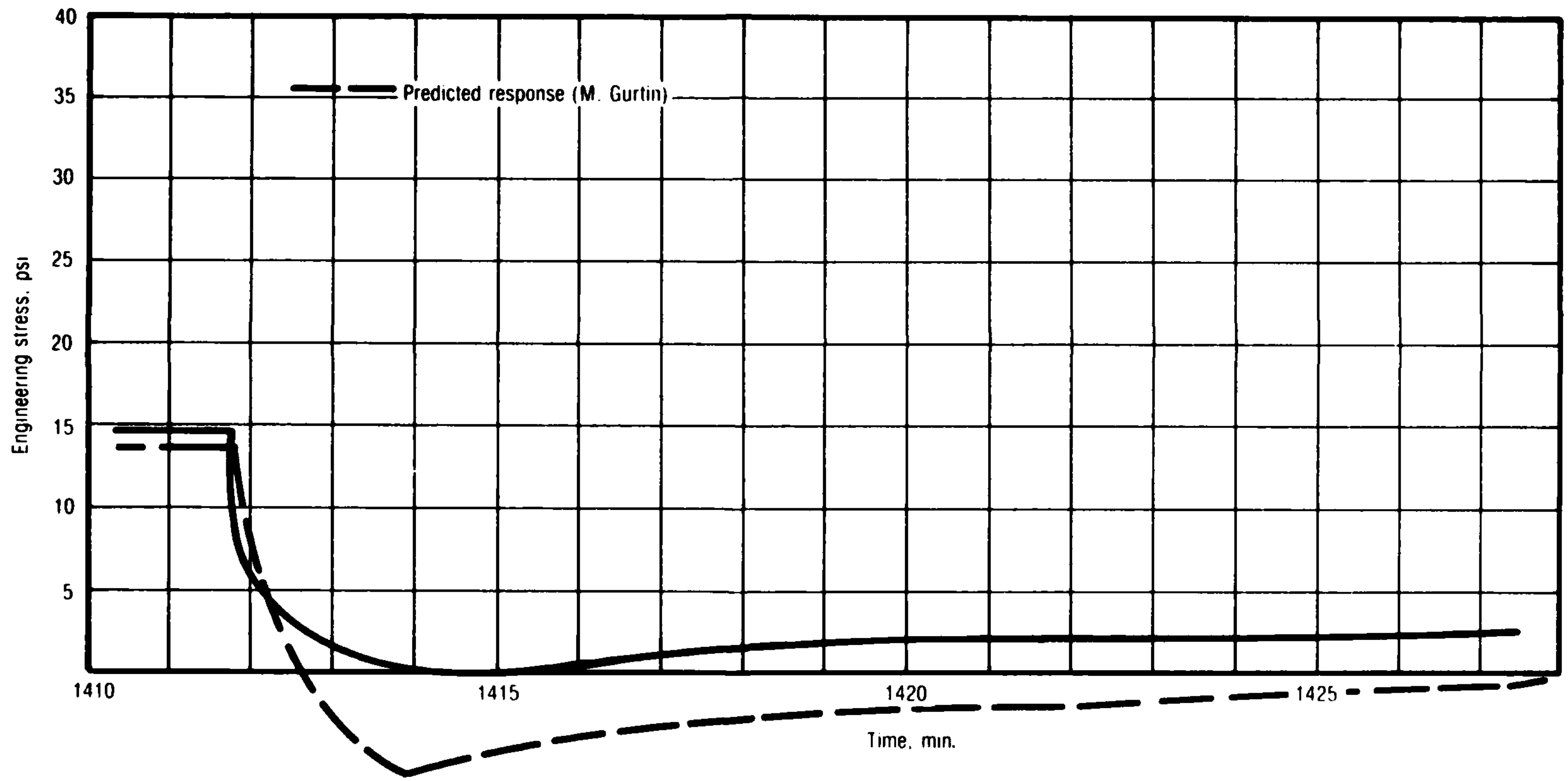


Figure 100. Relaxation-Unload-Reload of 6-in. Bar of UTP-19,360B-400/1777

28848

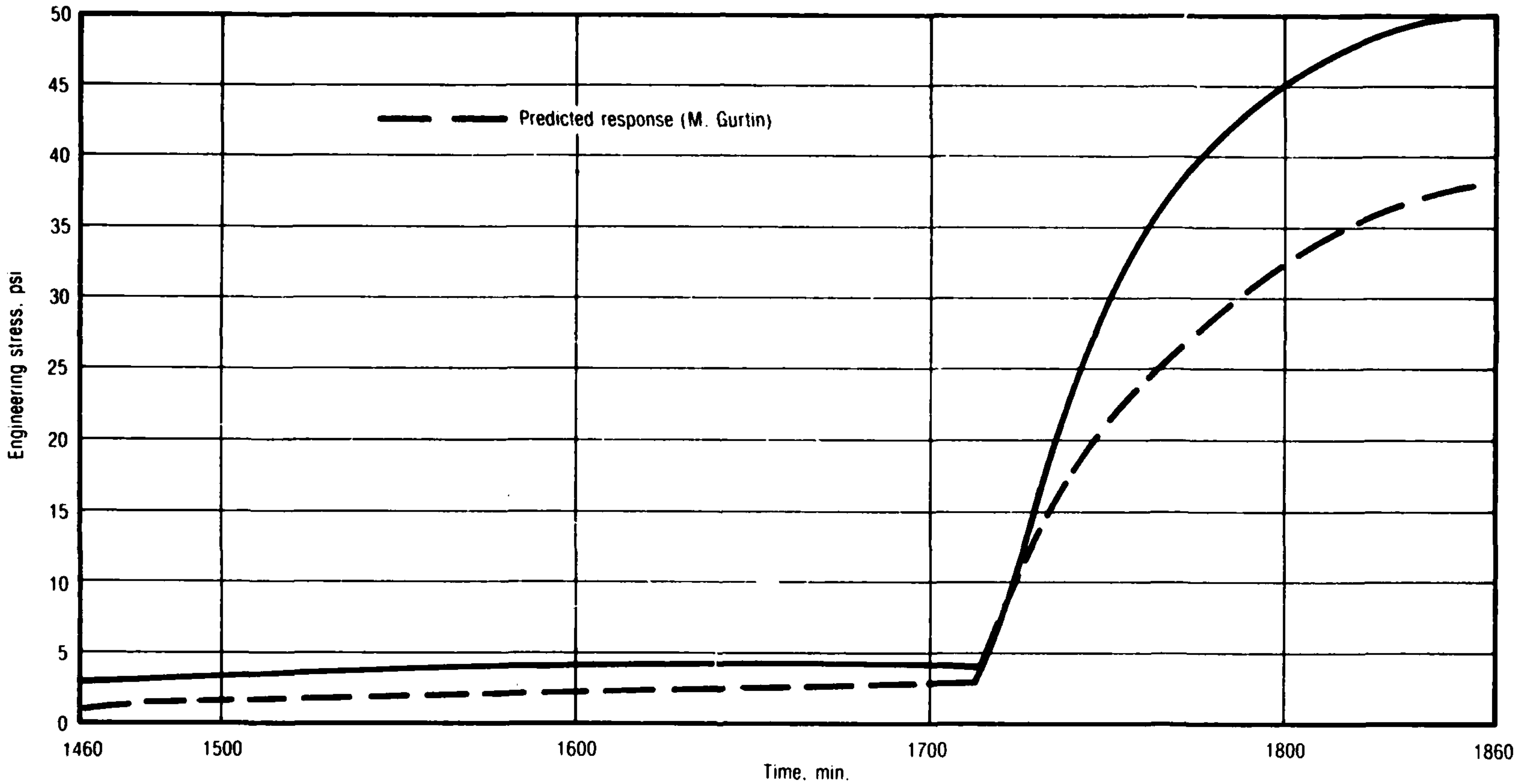


Figure 101. Relaxation-Unload-Reload of 6-in. Bar of UTP-19,360B-400/1777

28849

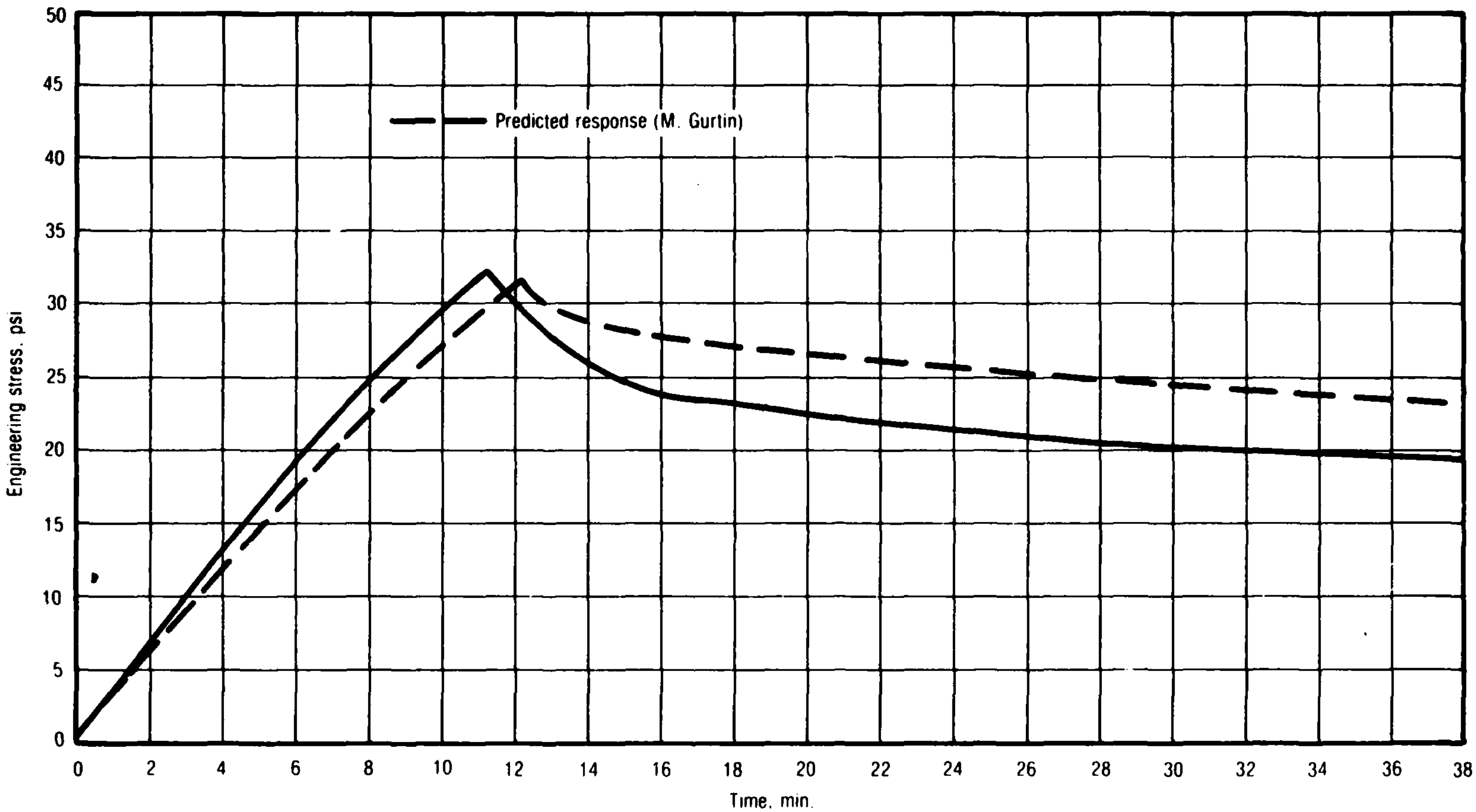


Figure 102. Three-Step Relaxation of 6-in. Bar of UTP-19,360B-400/1777

28850

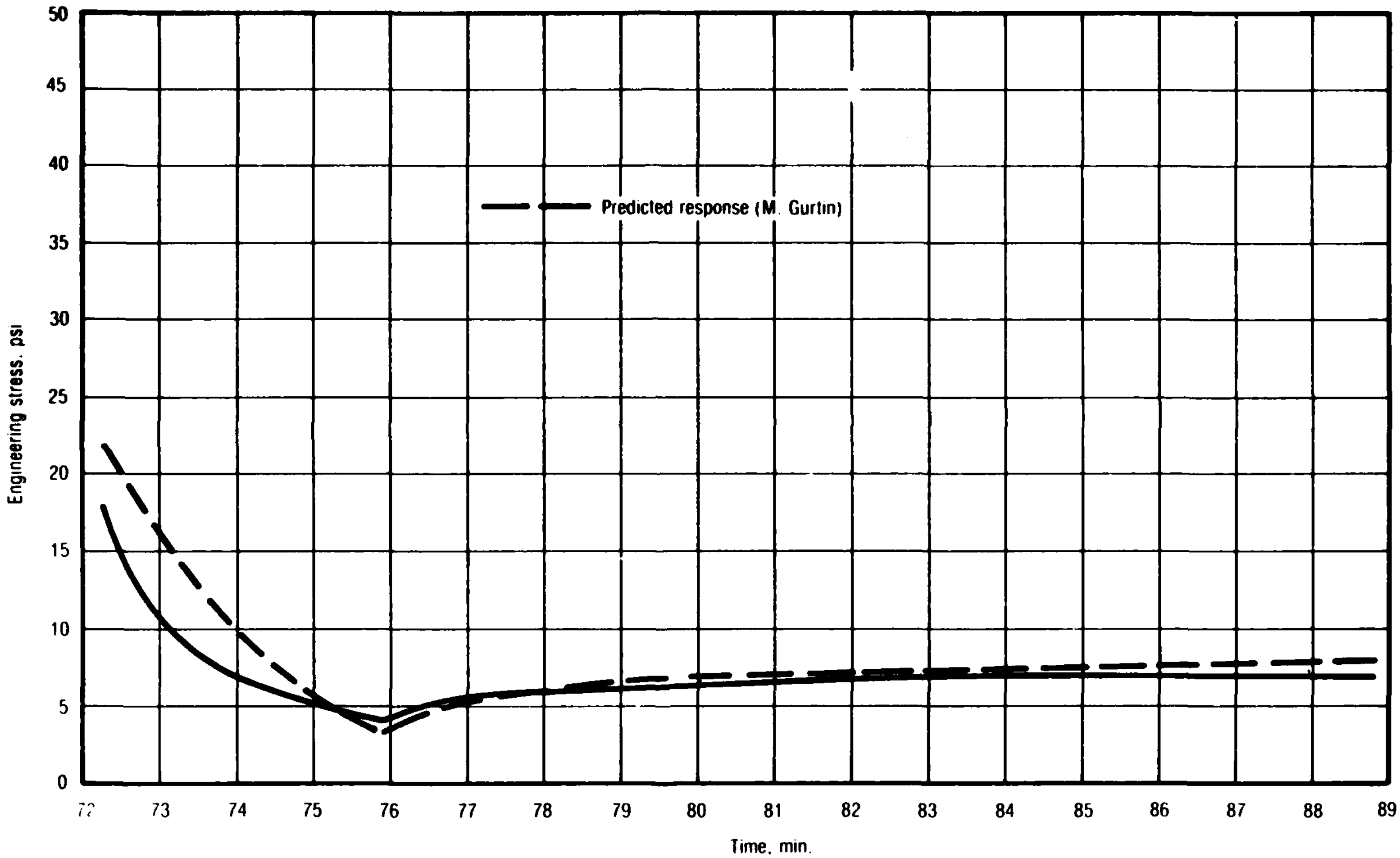


Figure 103. Three-Step Relaxation of 6-in. Bar of UTP-19,360B-400/1777

28899

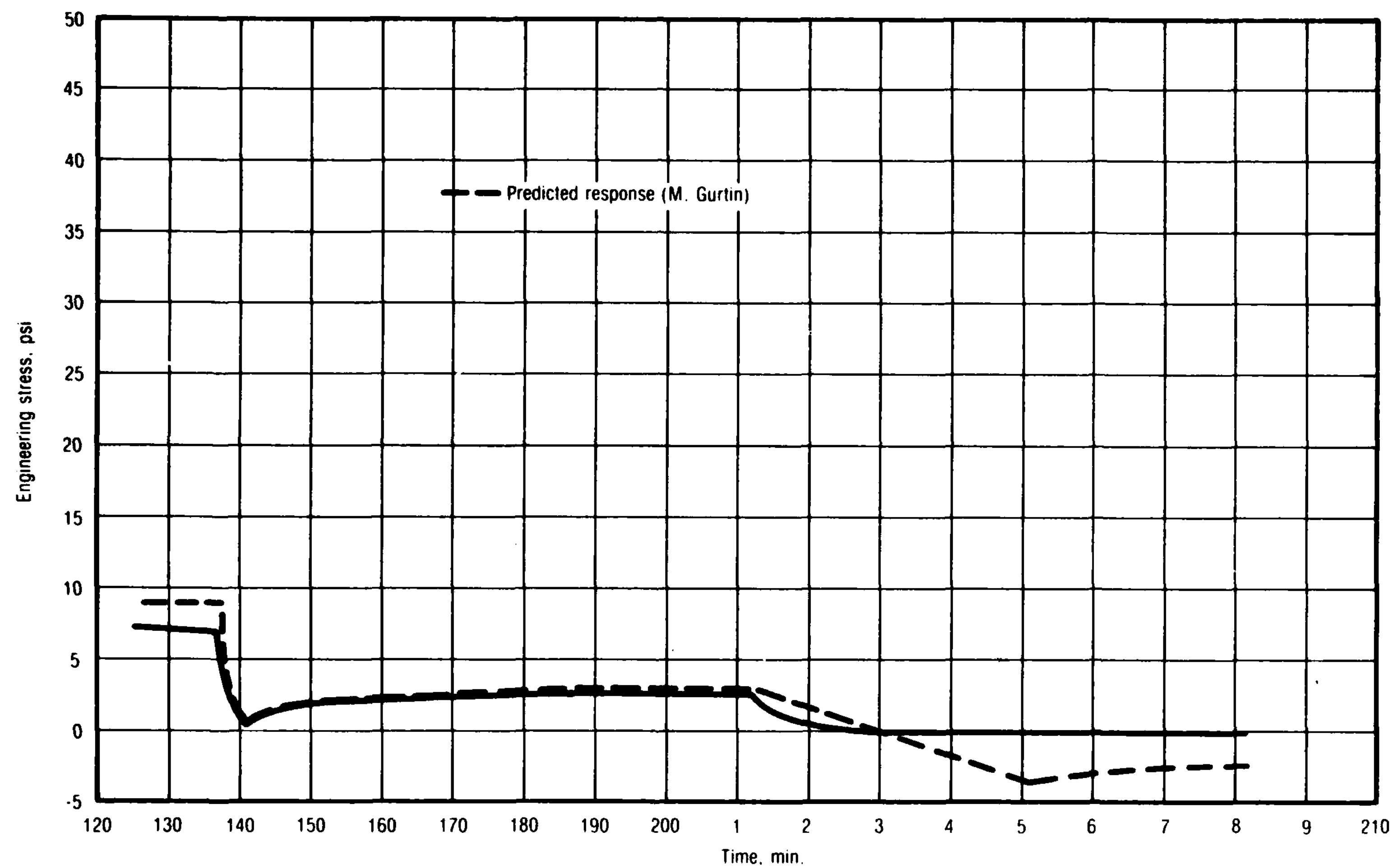


Figure 104. Three-Step Relaxation of 6-in. Bar of UTP-19,360B-400/1777

28900

$$\sigma_r(t) = \int_o^t G_T(\tau)\, \dot{\epsilon}\, (t - \tau)\, d\tau \tag{105}$$

and the correction stress, σ_c, given by:

$$\sigma_c\, (t) = \int_o^t G_c\left[\epsilon\, (\tau),\, \tau\right]\dot{\epsilon}(t - \tau)\, d\tau \tag{106}$$

Hence, to characterize the virgin response, only constant rate tests need be employed. In this instance, σ and σ_r are known, so that from equation (88), σ_c may be computed, and equated to equation (90) using the fact that $\dot{\epsilon}$ is a constant; i.e.:

$$\sigma(t) - \sigma_r\, (t) = \sigma_c\, (t) \equiv \int_o^t G\left[\epsilon\, (\lambda),\, \lambda\right] d\lambda \tag{107}$$

which, upon recalling equations (91) and (92) becomes:

$$\sigma(t) - \sigma_r\, (t) = \sum_{n\, =\, 1}^{N} \psi_n\, (t) \tag{108}$$

where:

$$\psi_n\, (t) = \sum_{p\, =\, 1}^{P} A_{np}\dot{\epsilon} \int_o^t \epsilon^p(\lambda)\, e^{-\lambda/\tau_n}\, d\lambda \tag{109}$$

Furthermore, since for a constant-rate test:

$$\epsilon(\lambda) = \dot{\epsilon}\lambda \tag{110}$$

it follows that:

$$\Psi_n\, (t) = \sum_{p\, =\, 1}^{P} A_{np}\dot{\epsilon}^{\,p+1} \int_o^t \lambda^p\, e^{-\lambda/\tau_n}\, d\lambda \tag{111}$$

and after integrating by parts:

$$\Psi_n (t) = \sum_{p=1}^{P} A_{np} \dot{\epsilon}^{p+1} \tau_n^{p+1} f_p (t/\tau_n) \tag{112}$$

with

$$f_o (x) = 1 - e^{-x} \tag{113}$$

$$f_p (x) = -x^R e^{-x} + pf_{p-1} (x) \; ; \; p = 1, \ldots P$$

Clearly, equations (89) and (92) to (94) may be used to determine the coefficients a_{np} appearing in the definition of the correction modulus. The procedure suggested by M. Gurtin to accomplish this is as follows:

1. Take N tests with constant rates $\dot{\epsilon}_1, \dot{\epsilon}_2, \ldots, \dot{\epsilon}_N$; and set:

$$\tau_i = \frac{1}{\dot{\epsilon}_i} ; \; i = 1, \ldots, N \tag{114}$$

2. Select the degree, P, of the series expansion of the correction modulus, as it appears in equation (87).
3. Use the $\dot{\epsilon}_1$ test and the approximation:

$$\sigma_c (t) = \Psi_1 (\dot{\epsilon}_1, t) \tag{115}$$

   to find the a_{1p}.
4. Use the $\dot{\epsilon}_2$ test and the approximation:

$$\sigma_c (t) - \Psi_1 (\dot{\epsilon}_2, t) = \Psi_2 (\dot{\epsilon}_1, t) \tag{116}$$

   to find the a_{2p}.
5. Use the $\dot{\epsilon}_3$ test and the approximation:

$$\sigma_c(t) - \Psi_1\,(\dot{\epsilon}_3,\ t) - \Psi_2\,(\dot{\epsilon}_3,\ t) = \Psi_3\,(\dot{\epsilon}_3,\ t) \tag{117}$$

to find the a_{3p}, and so on for the a_{4p} . . . a_{Np}.

6. Iterate this procedure if necessary; that is, define:

$$\overline{\Psi}(\dot{\epsilon},\ t) = \sum_{n=1}^{N} \Psi_n\,(\dot{\epsilon},\ t) \tag{118}$$

so that Ψ is known. For each ramp test, define:

$$\overline{\sigma_c} = \sigma_c - \overline{\Psi} \tag{119}$$

and repeat the above procedure using $\overline{\sigma}_c$ to find constants $\overline{a_{np}}$. The new values of the a_{np} are:

$$(A_{np})_{new} = A_{np} + \overline{A}_{np} \tag{120}$$

7. Repeat the process if necessary.

It is important to point out here that numerical difficulties may be encountered in applying this technique to characterizing the virgin response of solid propellants. In fact, some convergence problems were faced in connection with the UTP-19,360B data. Moreover, characterization of the damaged response calls for a large number of cyclic tests over a wide range of rates. This increases the convergence difficulties. The model was employed with the constant-rate tests only for this reason. Figures 105 to 108 show the results of the stress predictions obtained with the current version of the model. The first two plots correspond, respectively, to the lowest and highest rates available in the data base at ambient temperature.

So far in the program, none of the models developed by Gurtin has taken into account the effects of temperature on propellant response. However, the

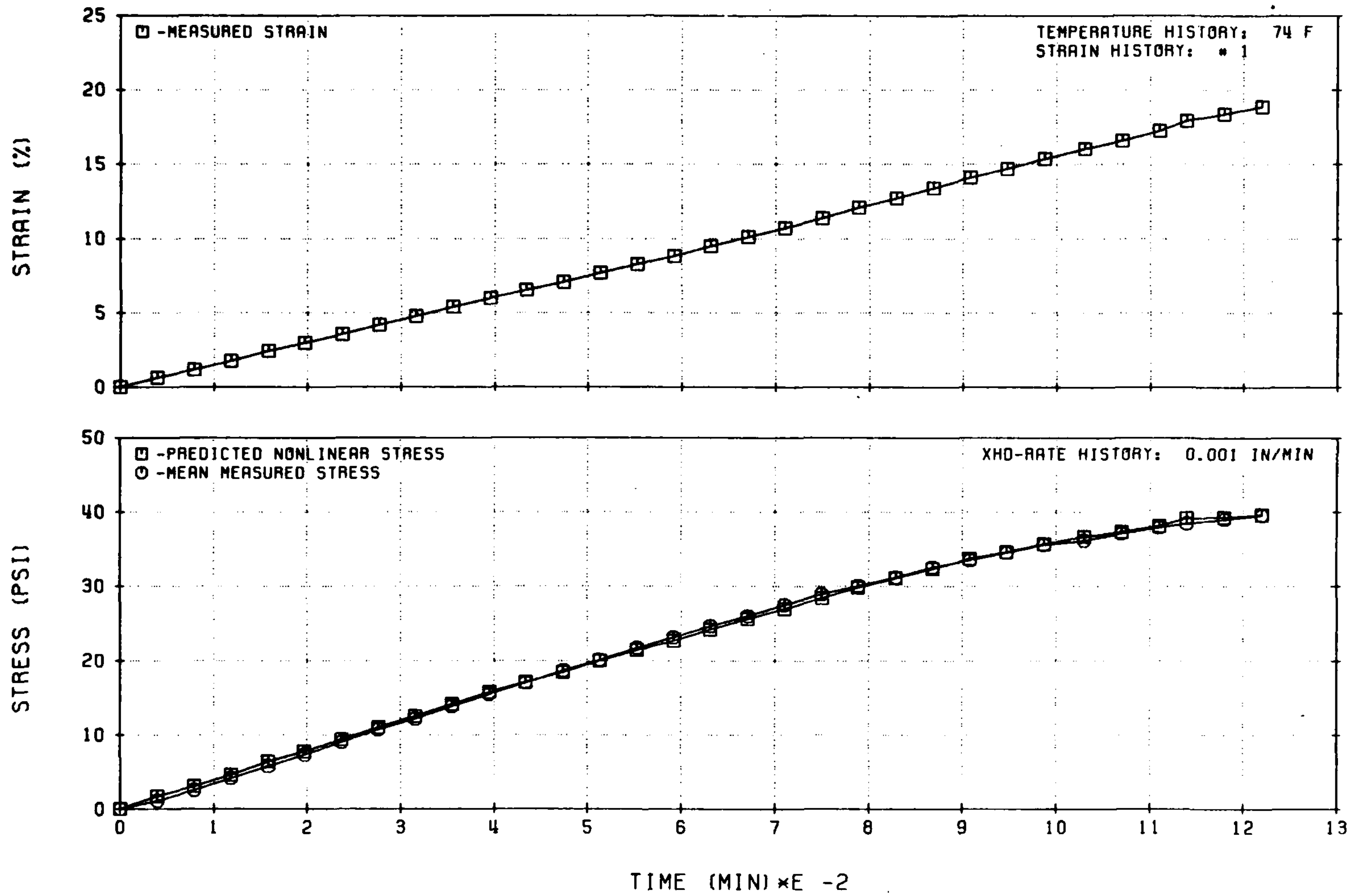


Figure 105. Nonlinear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 at 0.001 in./min and 74 F (M. Gurtin's Theory)

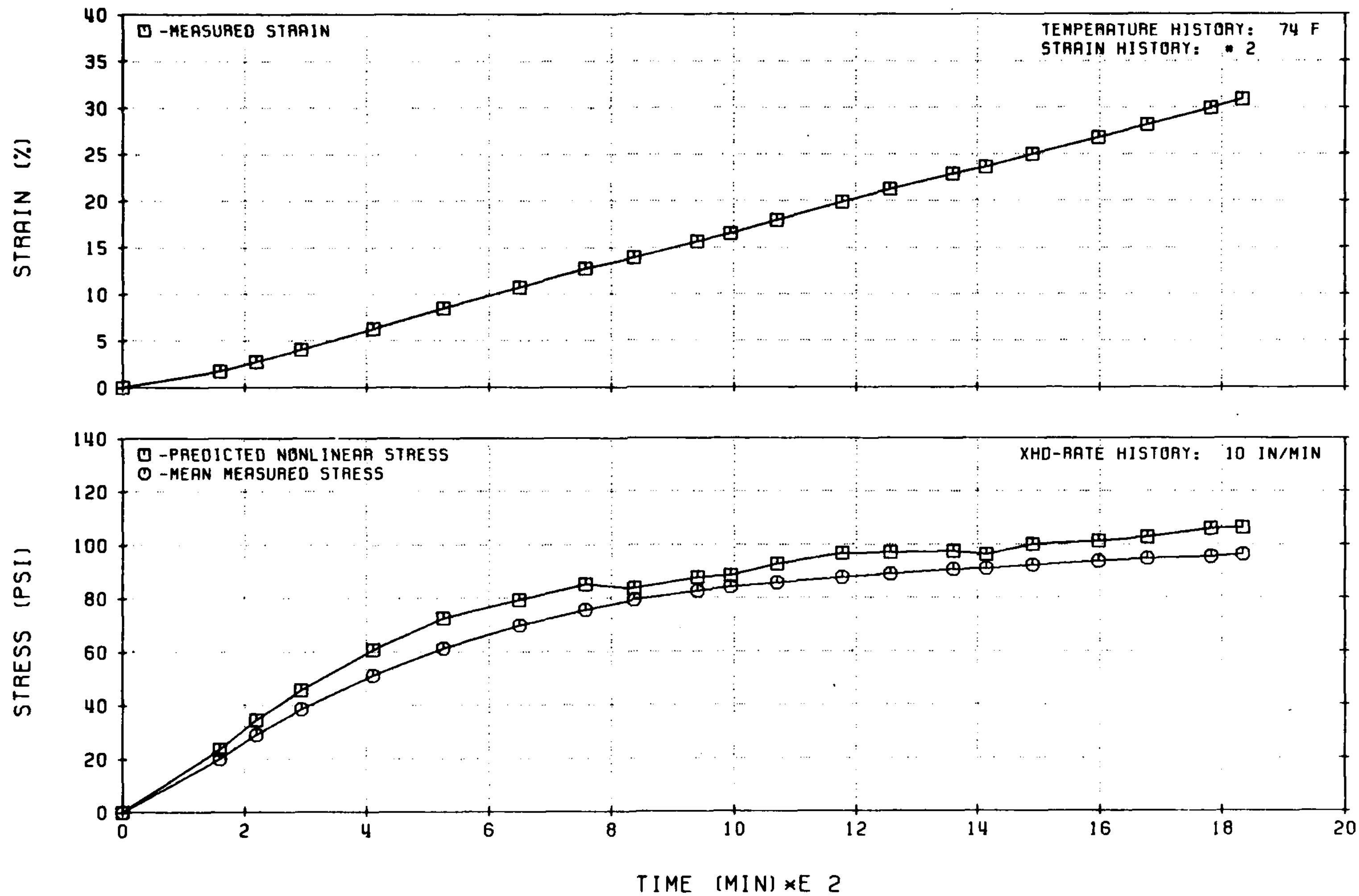


Figure 106. Nonlinear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 at 70 F (M. Gurtin's Theory)

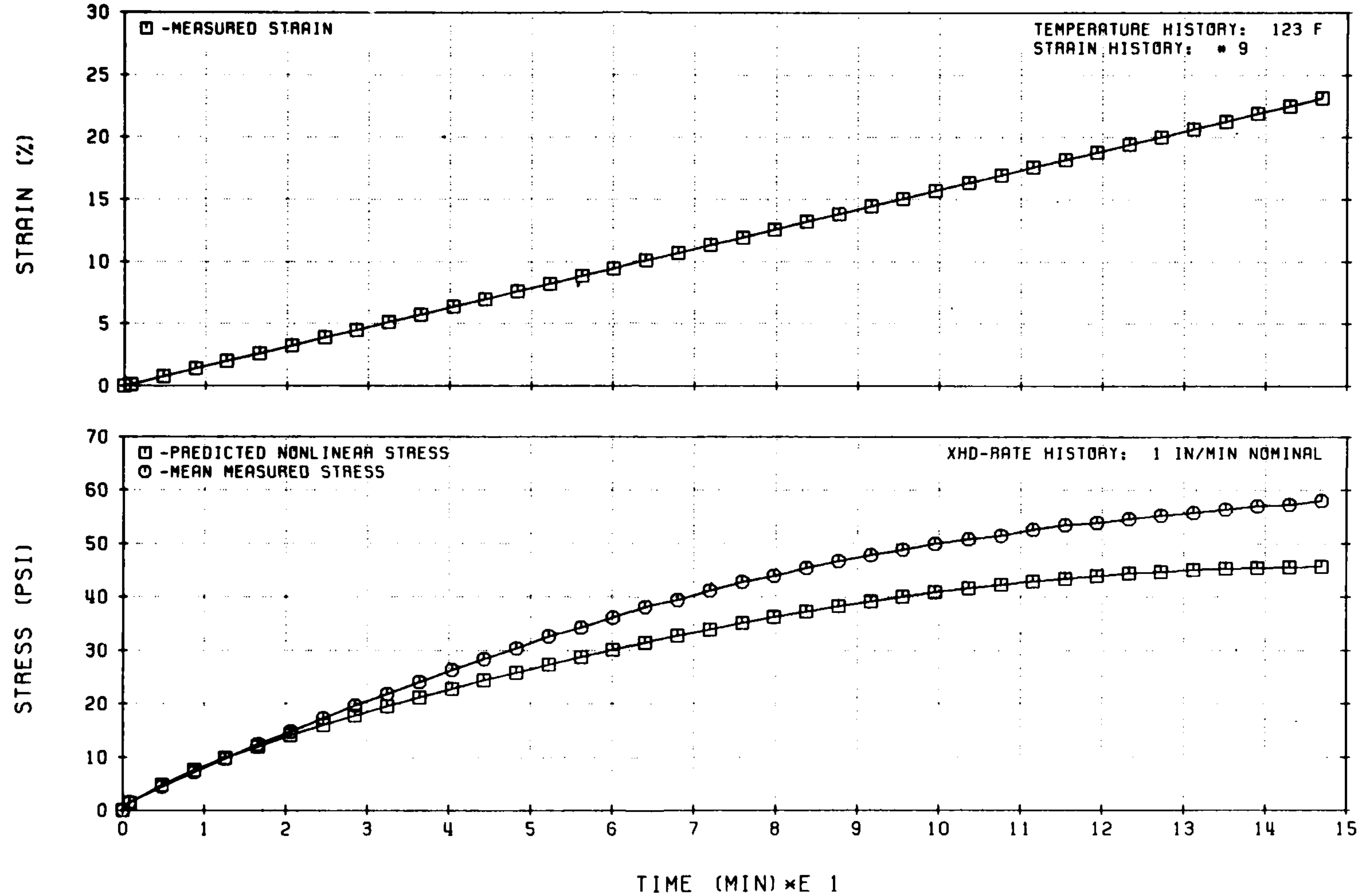


Figure 107. Nonlinear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 at 123 F (M. Gurtin's Theory)

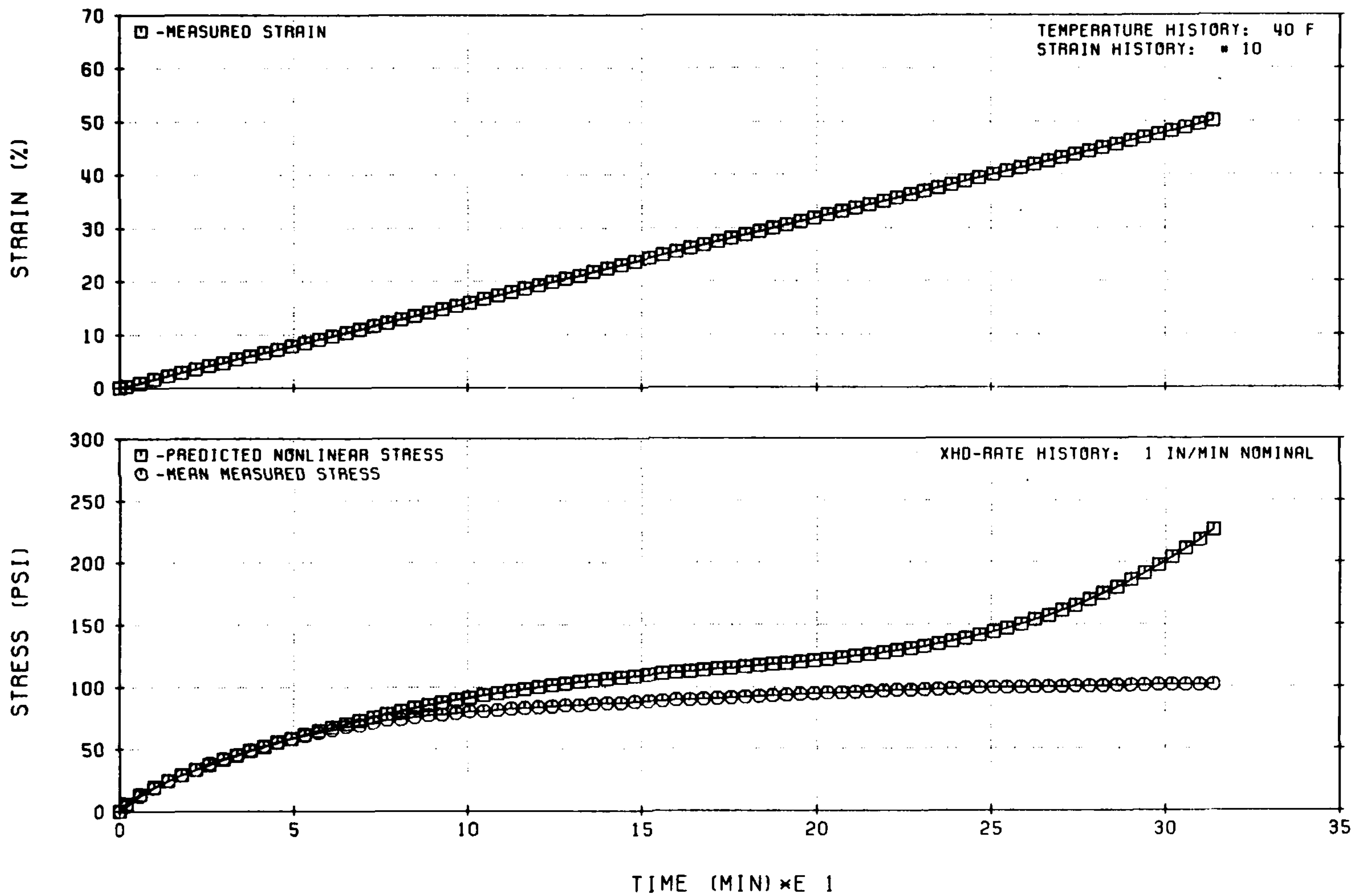


Figure 108. Nonlinear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 at 40 F (M. Gurtin's Theory)

time-temperature superposition principle was tested with the current version of the theory. The results appear in Figures 107 and 108 for the thermal tests at 123 and 40°F, respectively. The use of the superposition principle breaks down at a strain of about 39%. This was apparently due to the ambient temperature data base being limited to a low strain level. Also, it might be necessary to allow the relaxation function (G_c) to depend on the glass transition temperature (T_g)

$$G_c = G_c(\epsilon, T_g, t)$$

4.2.5 Russian Approach to Physically Nonlinear Viscoelastic Solids

The Russians have explored two approaches for characterizing damage effects in solid propellants (References 7 and 8). They are a general functional approach, and a kinetic equation of evolution for damage. Both approaches are based on internal-variable concepts, and either approach appears general enough to also incorporate cumulative damage and propellant response under multiaxial stress states. However, the general functional approach may be of little practical engineering value, because a very extensive testing program may be required to evaluate material parameters. This approach requires introduction of damage measures, which should reflect microstructural damage mechanisms, and a damage functional which characterizes the accumulation of damage or defects. The damage functional is then expanded into a series of multiple integrals in an analogous fashion to that followed by Green and Rivlin for nonlinear materials with fading memory. Herein lies the difficulty. Even assuming isotropy, four to six different types of multi-axial tests are required to evaluate the required material property functions for a first-order theory. Although the approach has theoretical merit and may even have some practical application in the future, its pursuit was abandoned in favor of the kinetic approach.

The essential feature of the kinetic approach is to introduce the degree of damage into the constitutive equations as a reduced-time parameter in the same way that temperature is introduced as a reduced-time parameter for the thermorheologically simple materials in linear thermoviscoelasticity. Damage is then defined in terms of some strength parameter of the material, and the degree of

damage is characterized through an equation of evolution for damage, as explained subsequently.

4.2.5.1 Original Model

The one-dimensional constitutive equation taken from the Russian literature by W. L. Hufferd as a means of predicting the response of physically nonlinear viscoelastic materials may be expressed by:

$$\sigma(t) = \int_{0}^{t} E\,(t' - \tau')\,\frac{d\epsilon}{d\tau}(\tau)\,d\tau \qquad (121)$$

where

σ = stress

ϵ = strain due to mechanically applied stress

$E(t)$ = relaxation modulus

$E(t) = E_e + E_2 t^{-n}$

and

$$t' - \tau' = \int_{\tau}^{t} \frac{d\epsilon}{a_\eta\left[\eta\ (\xi)\right]} \qquad (122)$$

represents the damage-reduced time, which is arrived at in the manner described next.

First, a normalized damage function $\omega = \omega(t)$ is introduced through the following kinetic equation of evolution:

$$\frac{d\omega}{dt}(t) = h\ (\omega)\ f(t) \qquad (123)$$

in which it is further assumed that:

$$f(t) = \int_{0}^{t} F(t - \tau)\ \phi\left|\sigma_0(\tau)\right| d\tau \qquad (124)$$

together with the conditions:

$$\omega(o) = 0$$
$$\omega(t^*) = 1 \tag{125}$$

indicating that no damage exists at the initial state, and that failure occurs at time t^*.

Next, equation (97) is integrated with $\omega(o) = 0$, leading to:

$$\int_o^{\omega} \frac{d\omega}{h(\omega)} = \int_o^t f(\tau)\, d\tau \tag{126}$$

Setting $t = t^*$, so that $\omega(t^*) = 1$, and substituting equation (98) for $f(\tau)$, it is obtained that

$$\frac{\displaystyle\int_o^{t^*} d\xi \int_o^{\xi} F(\xi - \tau)\, \phi \left| \sigma_o\ (\tau) \right| d\tau}{\displaystyle\int_o^1 \frac{d\omega}{h(\omega)}} = 1 \tag{127}$$

If now the function $F(t)$ is assumed to have a power-law representation:

$$F(t) = F_o\ t^m \tag{128}$$

Equation (101) can be written in the form:

$$\frac{\int_{o}^{t^*} d\xi \int_{o}^{\xi} F_o(\xi - \tau)^m \phi\left|\sigma_o(\tau)\right| d\tau}{\int_{o}^{1} \frac{d\omega}{h(\omega)}} = 1 \tag{129}$$

and integrating with respect to ξ, assuming that the order of integration may be interchanged, one arrives at:

$$\frac{\frac{F_o}{1 + m} \int_{o}^{t^*} (t^* - \tau)^{1+m} \phi\left|\sigma_o (\tau)\right| d\tau}{\int_{o}^{1} \frac{d\omega}{h(\omega)}} = 1 \tag{130}$$

which, for the case where σ_o and $\phi\left[\sigma_o\right] = \phi\left[\sigma_o\right]$ are constant, becomes:

$$\frac{F_o \phi_o (\sigma_o)}{(1 + m)(2 + m)} \frac{(t_o^*)^{2+m}}{\int_{o}^{1} \frac{d\omega}{h(\omega)}} = 1 \tag{131}$$

where t^*_o is the time to failure under the constant stress σ_o. Thus equation (104), in this case, may be written as

$$(2 + m) \int_{o}^{t^*} (t^* - \tau)^{1+m} \frac{d\tau}{(t_o^*)^{2+m}} = 1 \tag{132}$$

If the time to failure under a constant stress, σ_o, has the power-law representation:

$$\sigma_o^{\alpha}\, t_o^{*} = \text{constant} = \beta \tag{133}$$

then equation (106) can be put in the form:

$$\int_{o}^{t^*} (t^* - \tau)^{1+m}\, \sigma_o^{\alpha(2+m)}\, d\tau = \frac{\beta^{2+m}}{2+m} \tag{134}$$

so that, motivated by equations (106) and (108), the degree of damage accumulation may be introduced through the expression:

$$\eta(t) = (2 + m) \int_{o}^{t} (t - \tau)^{1 + m} \frac{d\tau}{(t_o)^{2+m}} \tag{135}$$

in which, obviously:

$$\begin{aligned} \eta\,(o) &= 0 \\ \eta\,(1) &= 1 \end{aligned} \tag{136}$$

The function $\eta(t)$ can be related to the damage function, ω, by:

$$\eta = \frac{\displaystyle\int_{o}^{\omega} \frac{d\,\omega}{h(\omega)}}{\displaystyle\int_{o}^{1} \frac{d\,\omega}{h(\omega)}} \tag{137}$$

This means that η represents the relative damage in the load history for the power-law representation of t^*_o. From equations (107) and (108), equation (109) may be written as:

$$\eta(t) = \frac{2+m}{\rho^{2+m}} \int_0^t (t-\tau)^{1+m} \; \sigma_0{}^{\alpha(2+m)} \, d\tau \qquad (138)$$

and finally, the influence of damage is treated as a reduced variable by introducing the modified time, t', defined by

$$dt' = \frac{dt}{a\eta\left|\eta(t)\right|} \qquad (139)$$

on which equation (96) is based, and where the shift function due to damage, a_η, depends on the material at hand.

Despite its rather appealing physical and mathematical foundations, the original model did not do any better than Linear Viscoelasticity when it was used to predict the response of either TP-H1011 or UTP-19,360B. In those instances, a linear expression:

$$a_\eta = 1 - \eta \qquad (140)$$

and an exponential form:

$$a_\eta = e^{-\eta}$$

were used for the damage shift function.

The partial failure of the Russian approach to reproduce solid-propellant behavior made it necessary to change certain aspects of the theory, as explained next.

<u>Current Model</u>. One revised version of the Russian stress-strain law takes the form:

$$\sigma(t) = \int_0^t E\left(\frac{t-\tau}{a_\eta^*}\right)\frac{d\epsilon}{d\tau}(\tau)\, d\tau \qquad (141)$$

where a_η^* is a damage-related shift function, assumed to depend only on the current state of strain; specifically:

$$a_\eta^* = a_\eta^* \left[\epsilon(t), \quad \dot{\epsilon}(t)\right] \tag{142}$$

Clearly, if:

$$E(t) = E_e + E_2 t^{-n} \tag{143}$$

then equation (113) becomes:

$$\sigma(t) = E_e \, \epsilon(t) + (a_\eta^*)^n E_2 \int_0^t (t - \tau)^{-n} \frac{d\epsilon}{d\tau}(\tau) \, d\tau \tag{144}$$

which resembles the classical approach of the softening function used as a stress-correction factor.

Another revised version of the Russian approach consists of retaining most aspects of the original law, but constant strain-rate data are employed to express the time to failure as:

$$t_o^* = \left(\frac{\beta}{\dot{\epsilon}}\right)^\alpha \tag{145}$$

and equation (108) is changed to:

$$\eta(t) = \frac{(2 + m)}{\dot{\epsilon} \, t_o^*} \int_0^t (t - \tau)^{1+m} \phi(\tau) \, d\tau \tag{146}$$

where:

$$\phi(t) = \epsilon(t) = \dot{\epsilon} t$$

and

$$\eta(t^*) = 1$$

Thus, evaluation of equation (117) at $t = t^*$ yields:

$$\frac{(2 + m)}{\epsilon_{t_o^*}} \int_0^{t^*} (t^* - \tau)^{1+m} \phi(\tau) d\tau = 1 \qquad (147)$$

which, through a change of variables and after some algebraic manipulations, may be integrated to:

$$(t_o^*)^{2+m} = 3 + m \qquad (148)$$

The solution for m, as a function of strain rate, is easy to obtain using equations (116) and (119) (as presented in Figure 109 for UTP-3001).

In much the same way, integration of equation (117) for the relative damage function, $\eta(t)$, leads to:

$$\eta(t) = \left(\frac{t}{t_o^*}\right)^{3 + m} \qquad (149)$$

Hence, using constant strain-rate data to express the time to failure does simplify things, but a major assumption would still be needed regarding the form of the damage shift function as it was in the original set of equations. In this context, it is important to note that the linear expression:

$$a_\eta = 1 - \eta \qquad (150)$$

and the exponential form:

$$a_\eta = e^{-\eta} \qquad (151)$$

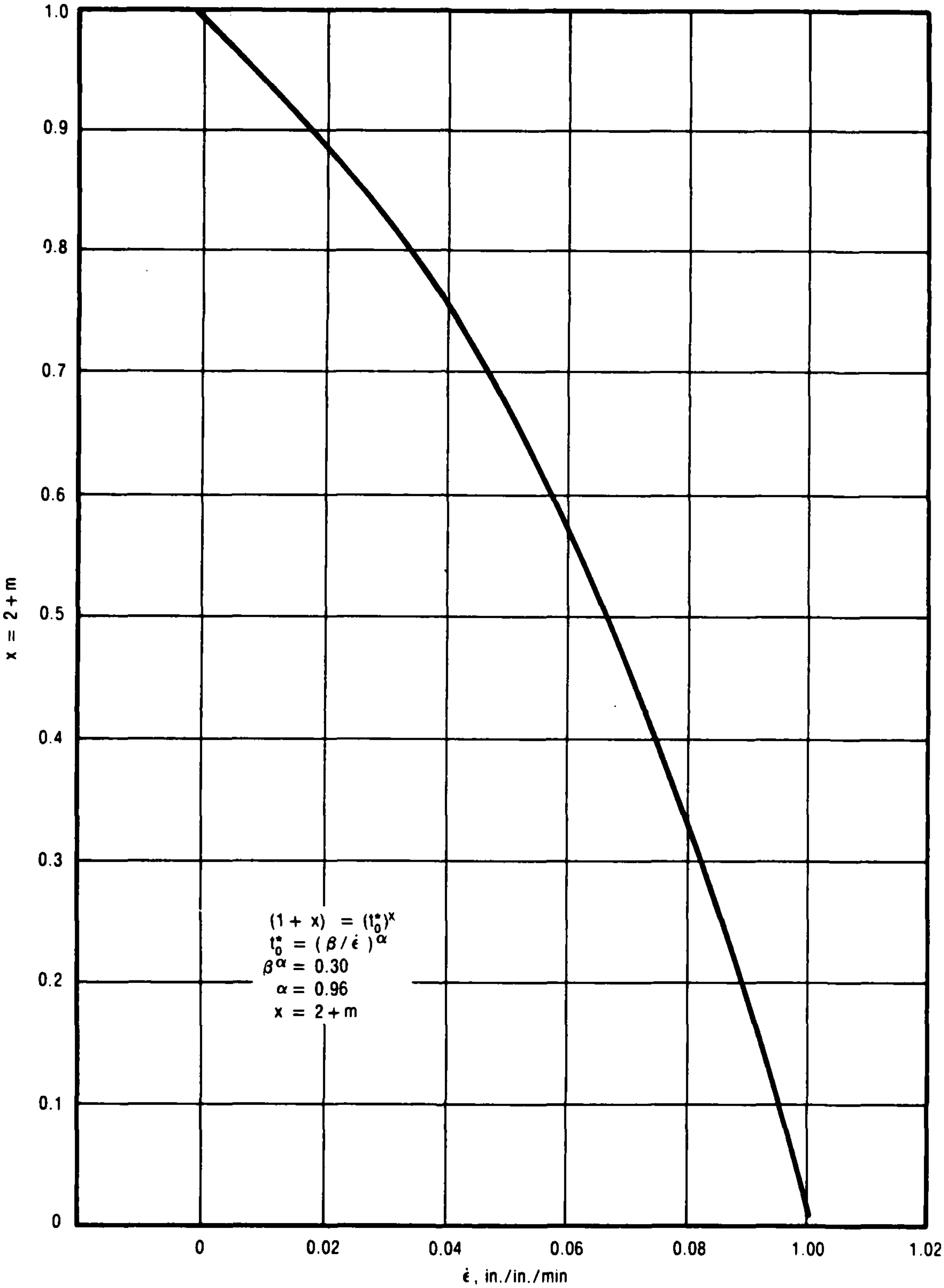


Figure 109. Solution for m as a Function of Strain Rate

28893

were used for the damage shift function without success. For this reason, the modified version used to run the stress predictions included in this report, corresponds to equation (115).

4.2.5.3 Stress Predictions

Figures 110 to 114 show the comparison between the observed response and that calculated using the present theory. As may be seen, the predicted response is quite accurate in all cases considered, which include constant- and dual-rate tests, as well as a short-duration similitude loading.

4.2.5.4 Material Characterization

As may be gathered from equation (115), the simplest version of this theory requires the knowledge of only two material-property functions, to wit:

1. The relaxation modulus, and
2. The damage shift function:

$$(a_\eta^*) \overset{\text{def}}{=} a_\eta = a_\eta \left[\epsilon(t), \ \dot{\epsilon}(t) \right] \tag{152}$$

which is determined in the following ways:

a. From constant strain-rate tests, to correct the stress response during loading;
b. From a relaxation test at a large strain level, to account for healing; and
c. From a constant strain-rate cycle carried out to a large strain level, to more adequately reproduce the hysteretic behavior of the propellant.

The damage shift functions corresponding to UTP-19,360B are shown in Figures 115 to 119. The first three of these plots represent typical curves of a_η for low, intermediate and high strain-rate tests, while Figures 118 and 119 give the correction curves for relaxation and unloading, respectively.

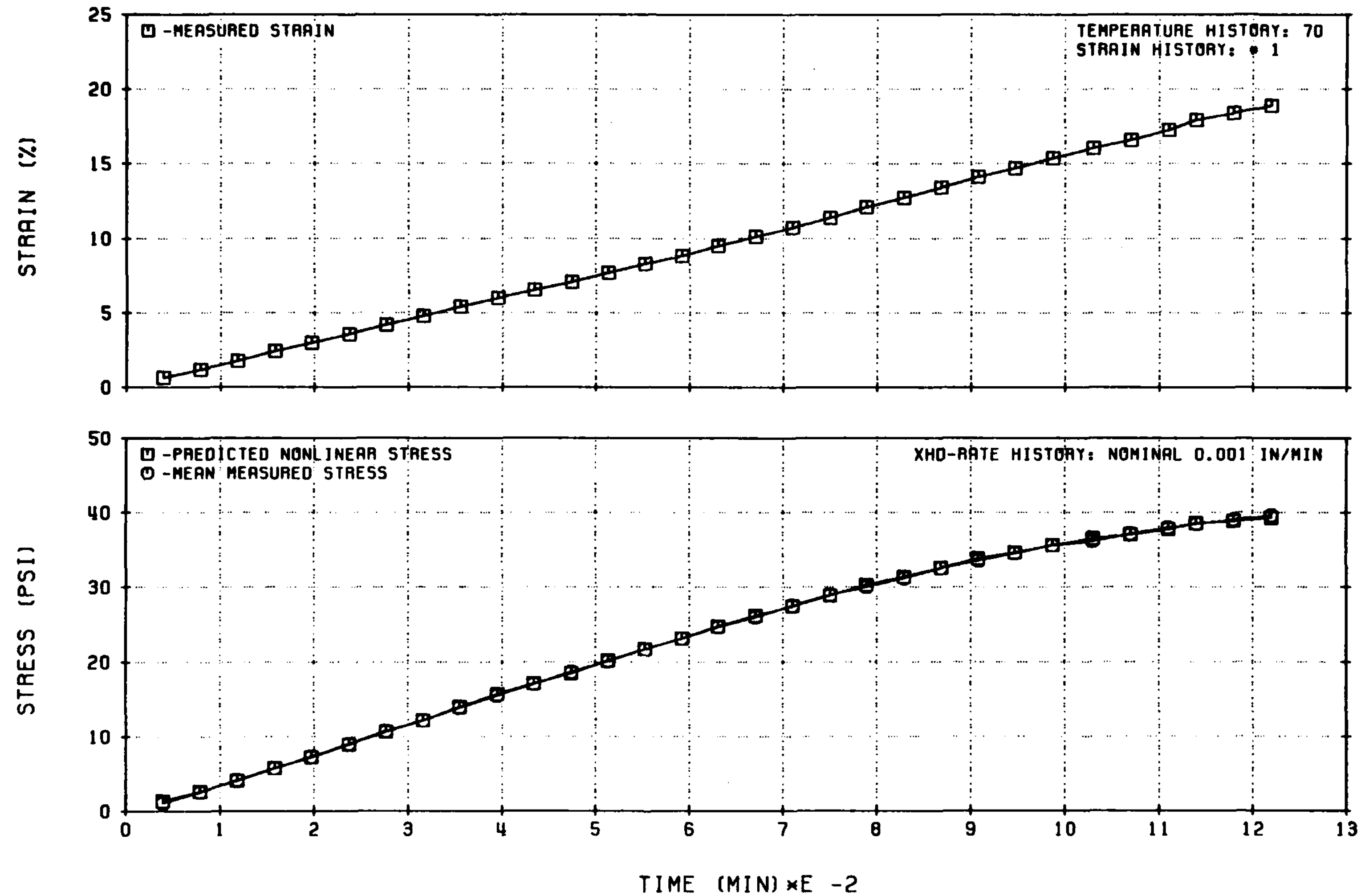


Figure 110. Nonlinear Viscoelastic Stress Predictions for UTP-19,360B-400/1777

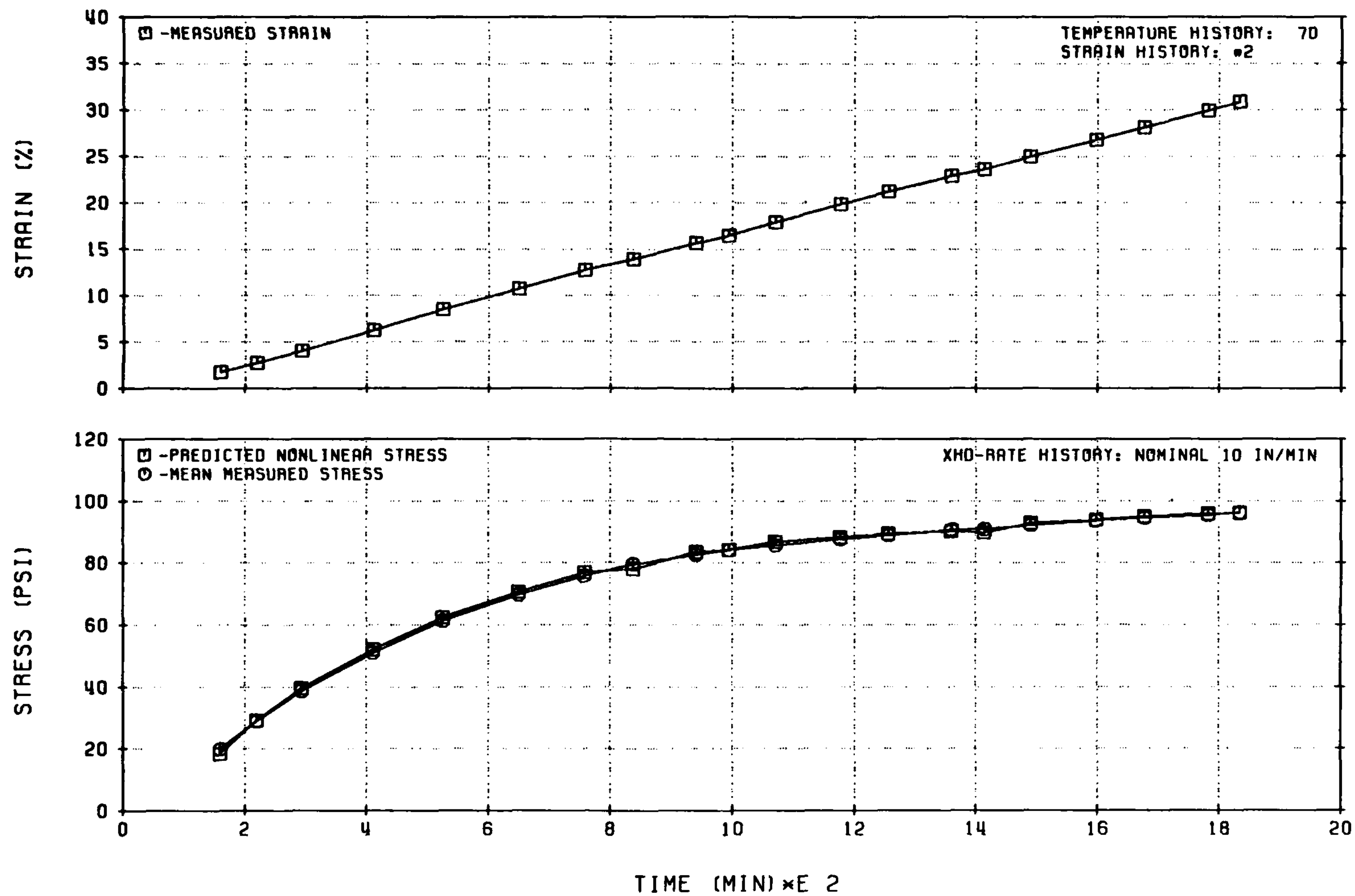


Figure 111. Nonlinear Viscoelastic Stress Predictions for UTP-19,360B-400/1777

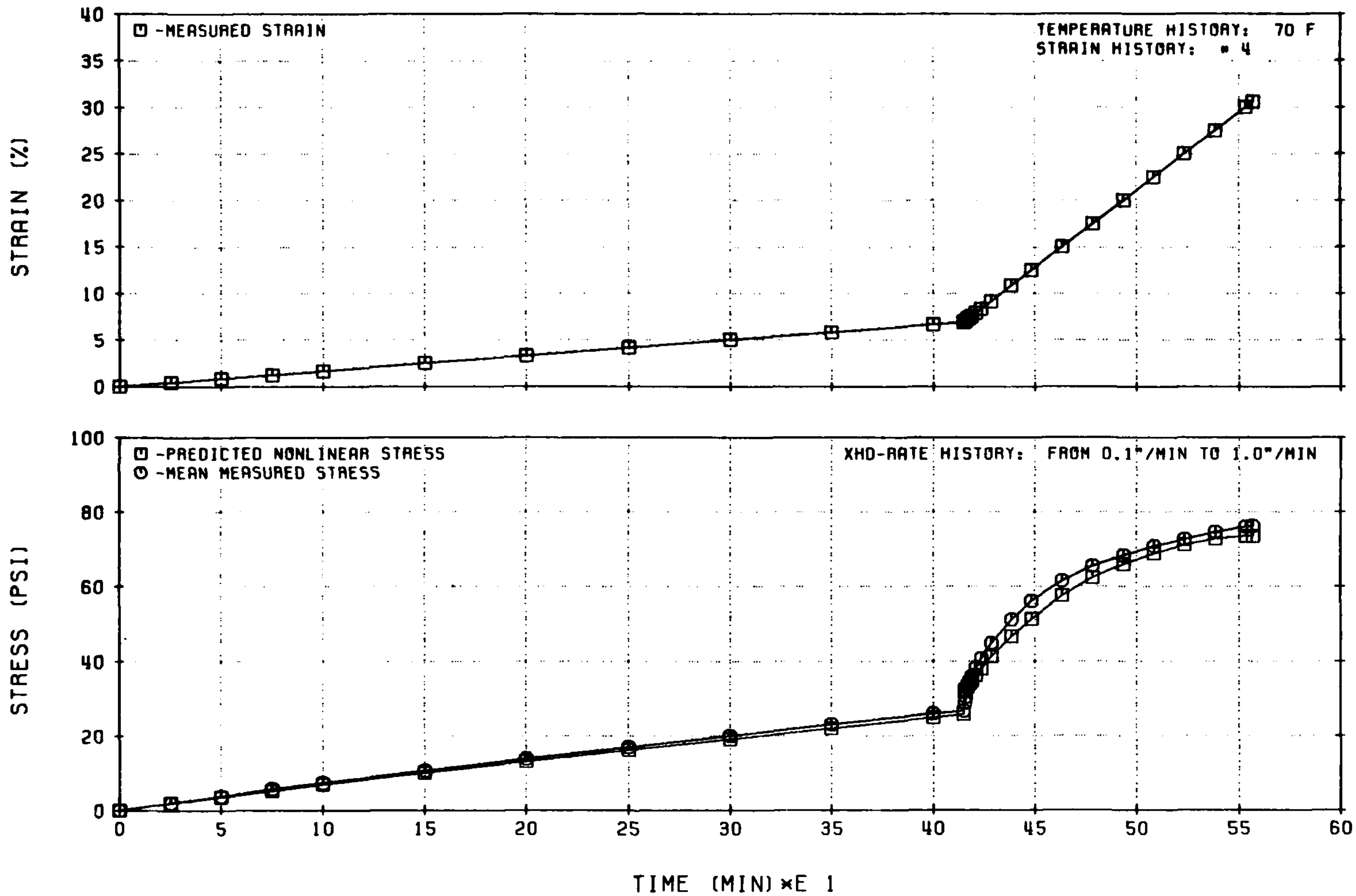


Figure 112. Nonlinear Viscoelastic Stress Predictions for Two-Rate Test (UTP-19,360B-400/1777)

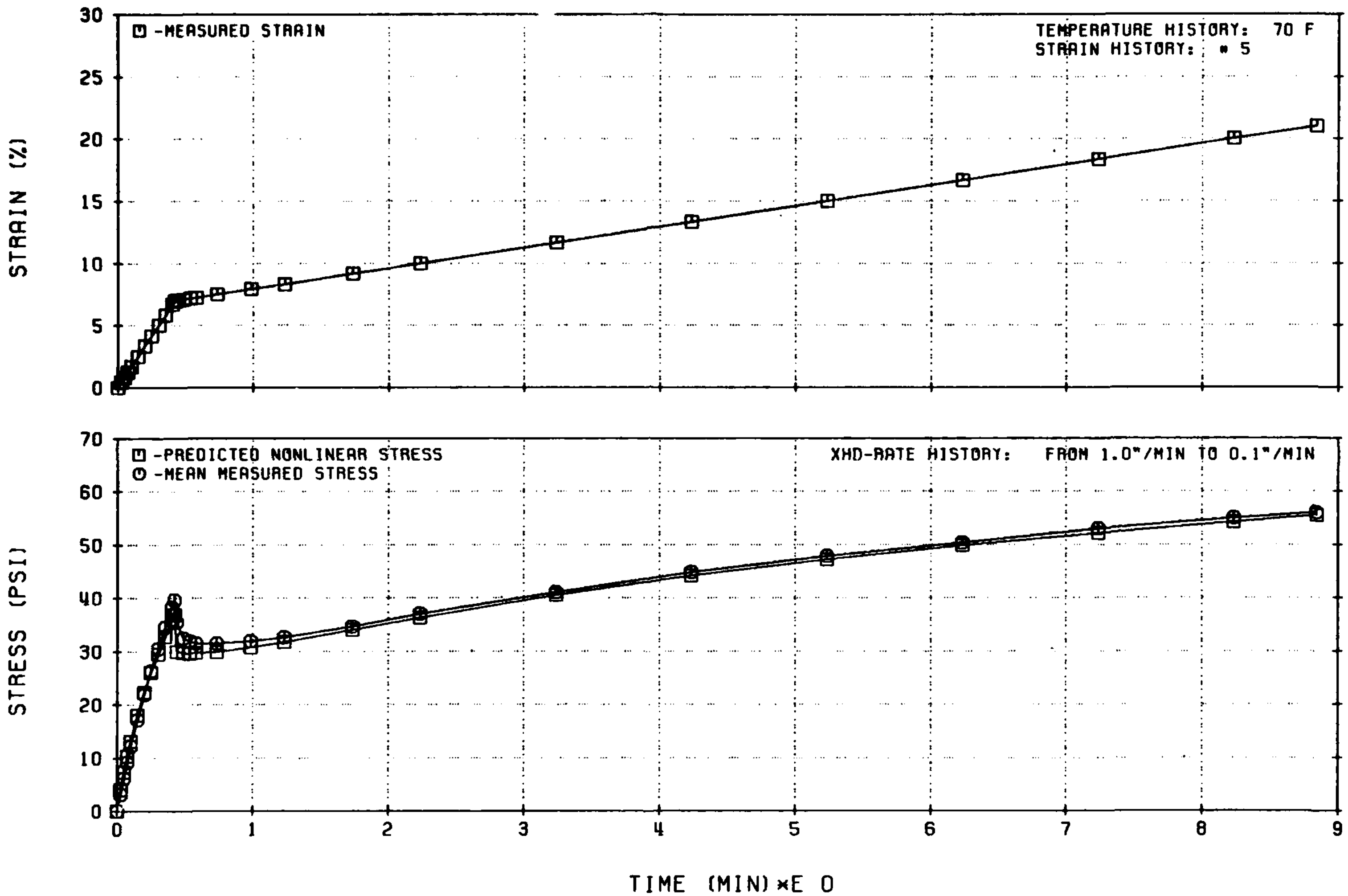


Figure 113. Nonlinear Viscoelastic Stress Predictions for Two-Rate Test (UTP-19,360B-400/1777)

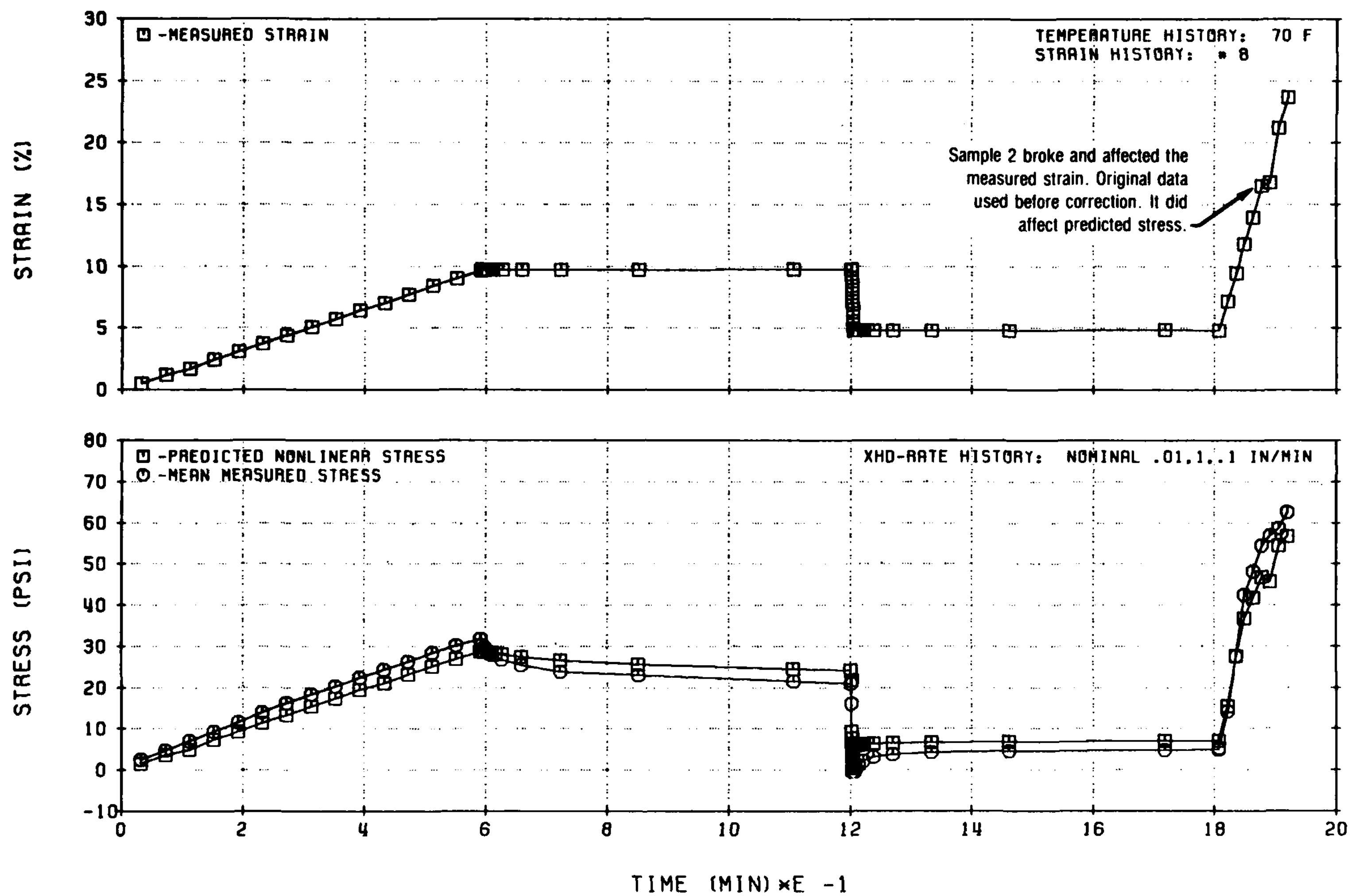


Figure 114. Nonlinear Viscoelastic Stress Predictions for Short Similitude Test (UTP-19,360B-400/1777) (W. L. Hufferd's Theory)

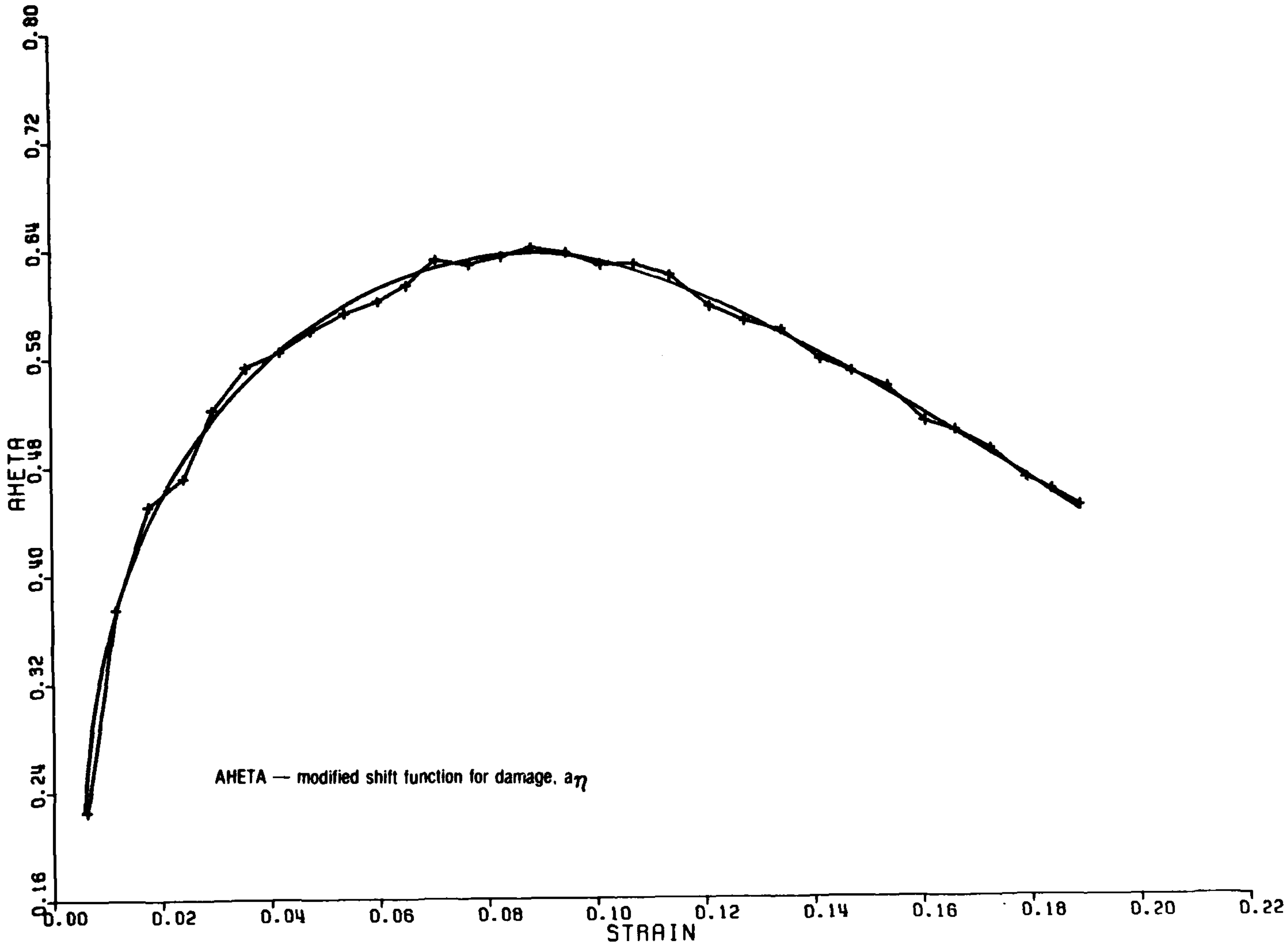


Figure 115. Constant Rate Test (0.001 in./min.)

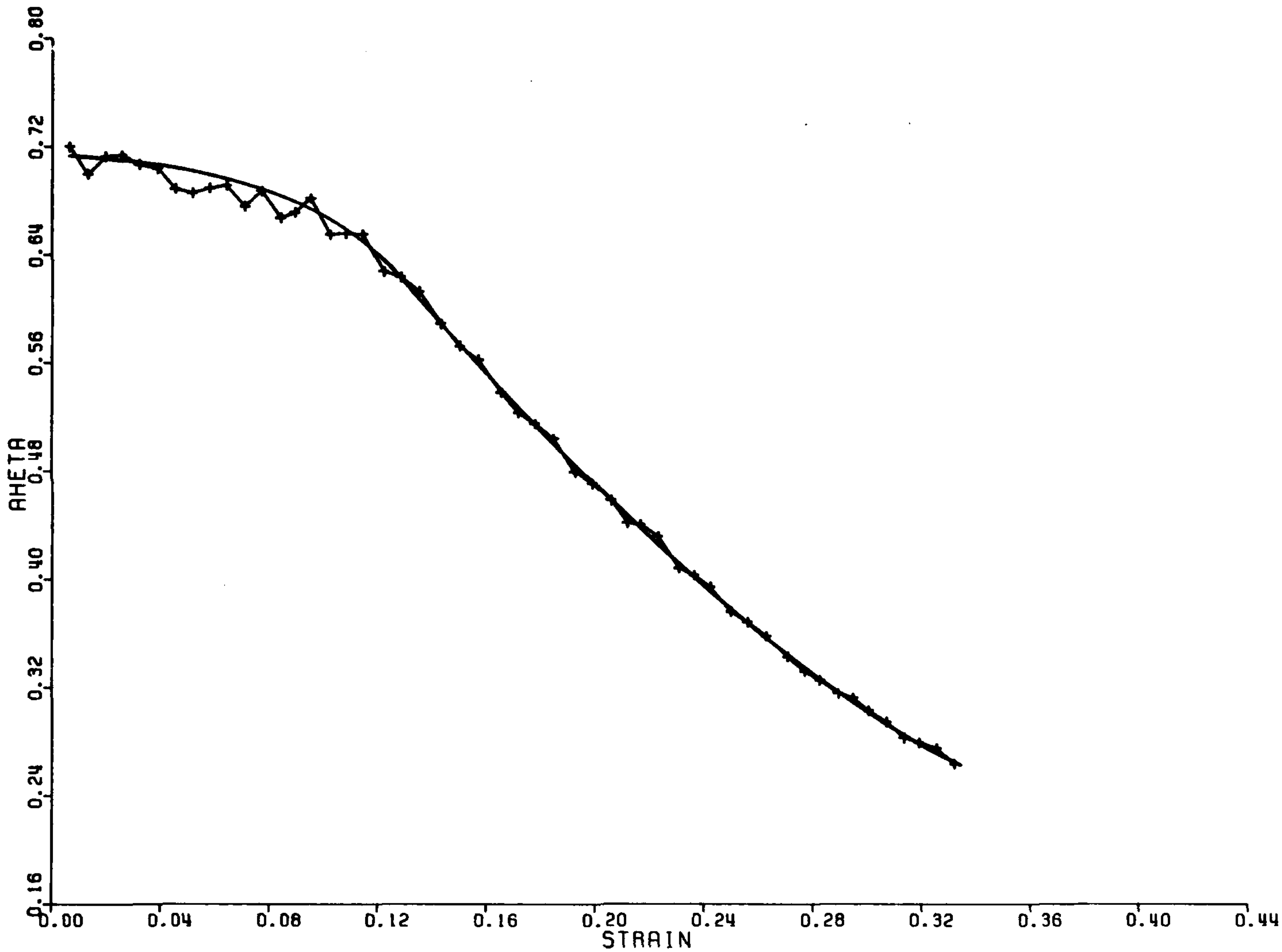


Figure 116. Constant Rate Test (0.1 in./min.)

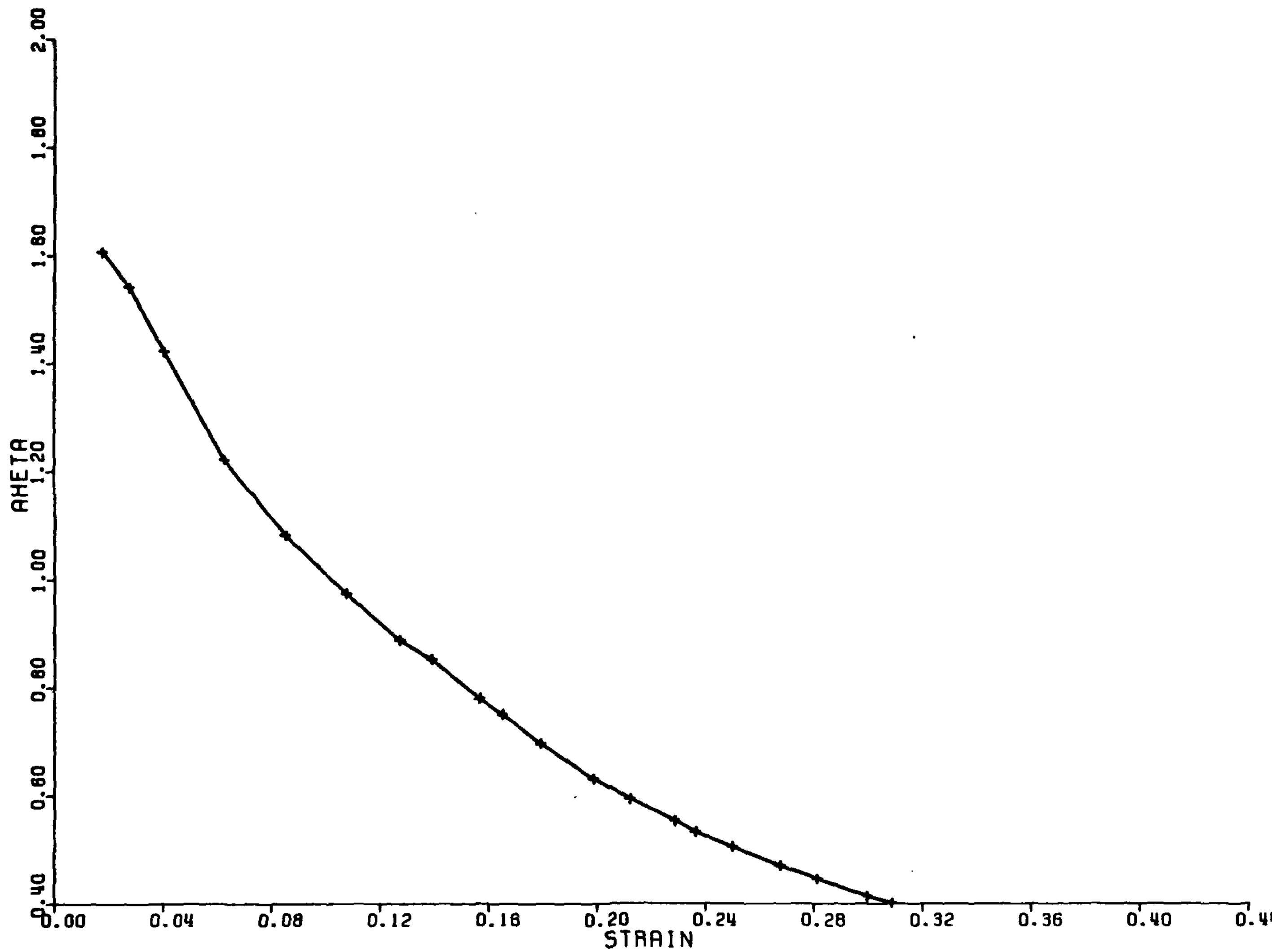


Figure 117. Constant Rate Test (10 in./min.)

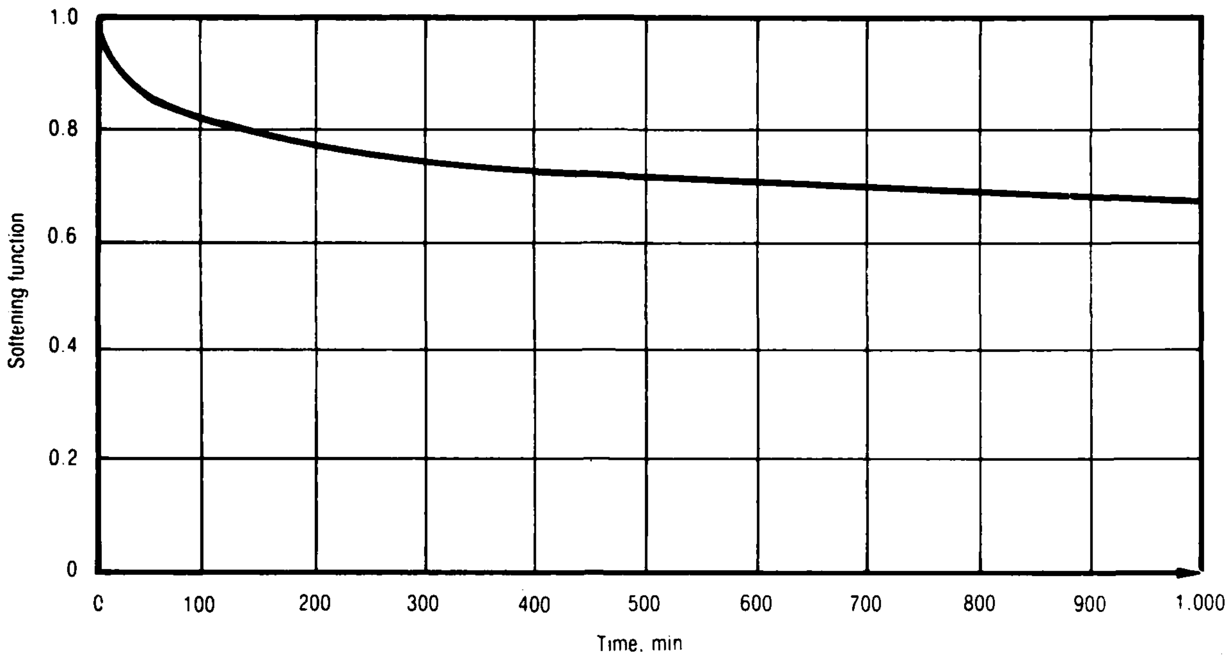


Figure 118. Softening Function During Relaxation

28894

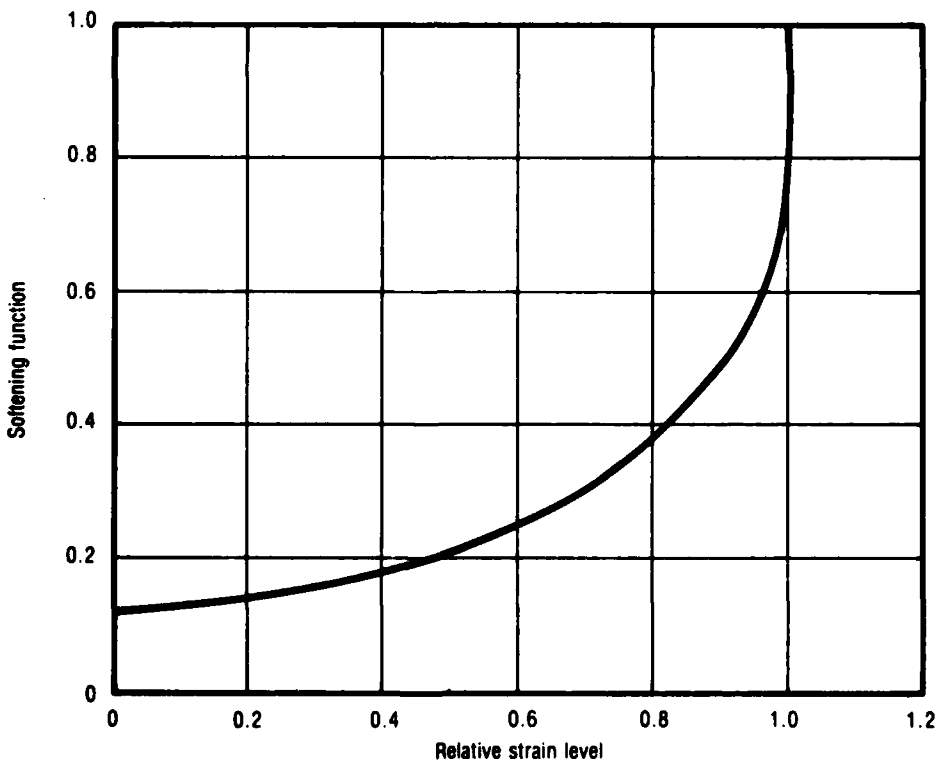


Figure 119. Softening Function During Unloading

28895

4.2.6 The Swanson Nonlinear Constitutive Law

4.2.6.1 Original Model

The framework for this theory was established by taking into account some typical behavior aspects of high-elongation propellants as indicated in Reference 9. The principal features considered were: (1) the usual viscoelastic dependence of the response on the strain rate, (2) the ability of the solid propellant to sustain large strains, (3) the marked deviation of the solid-propellant response from that associated with Linear Viscoelasticity, as evidenced by the large hysteresis exhibited under cyclic loading by many solid propellants, even at small strains, and (4) the dependence of the stress-strain response on superimposed pressure.

Although it is not essential to have done it this way, the capability of handling large strains was incorporated into the constitutive equations by using the cauchy-stress tensor (σ) as a measure of the state of stress at a point. Its conjugate, the left Cauchy-Green deformation tensor (B) was used as the measure of straining. The Cauchy stresses, defined in terms of force per unit deformed area, are also called "true" stresses. In a principal coordinate system, B takes on the diagonal form:

$$B = \begin{bmatrix} \lambda_1^2 & 0 & 0 \\ 0 & \lambda_2^2 & 0 \\ 0 & 0 & \lambda_3^2 \end{bmatrix} \tag{153}$$

in which the λ_i's are simply the extension ratios in the principal directions.

The remaining aspects of the observed response of solid propellant were modeled through the use of a softening function as a stress correction factor. The major constitutive assumption in this theory relates the second invariants of the deviatoric stress and deformation tensors through the equation:

$$\sqrt{II_{\sigma'}} = (f)\ (g) \tag{154}$$

This separable form has been used previously (References 11 and 29) and is motivated by the fact that the constant strain rate tensile curves are roughly similar.

In equation (122), f is the following viscoelastic function:

$$f = \int_0^t G\,(t - \tau)\,\frac{\partial\sqrt{II_{B'}}}{d\tau}\,d\tau \tag{155}$$

with G being the relaxation modulus in shear, taken in this theory as one third the tensile relaxation modulus, and:

$$\begin{aligned}
&g = \text{softening function}\\
&\sigma'_{ij} = \sigma'_{ij} - (\sigma_{kk}/3)\,\delta_{ij} = \text{deviatoric stress tensor}\\
&B'_{ij} = B_{ij} - (B_{kk}/3)\delta_{ij} = \text{deviatoric deformation tensor}\\
&II\alpha \equiv \left\{ -\left[\alpha_{11}\,\alpha_{22} + \alpha_{22}\,\alpha_{33} + \alpha_{33}\,\alpha_{11}\right] + \alpha_{12}^2 + \alpha_{23}^2 + \alpha_{31}^2 \right\}^{1/2}
\end{aligned} \tag{156}$$

Second invariant of tensor $\alpha = \sigma$, B

Now, g is a function of deformation and pressure (mean stress) and can be considered to be primarily a strain-softening function. It is defined as that function of the invariant $\sqrt{II_{B'}}$ that will force the viscoelastic Cauchy stress to coincide with the experimental results; thus, unloading hysteresis as well as the effects of pressure may be readily incorporated into this theory, simply by obtaining the corresponding forms of the softening function under such conditions.

The softening function corresponding to virgin loading is obtained by fitting the model to uniaxial tensile tests at constant cross-head speed. Under these conditions, the deviatoric stress invariant reduces to:

$$\sqrt{II_{\sigma'}} = \frac{\sigma_{11}}{\sqrt{3}} \tag{157}$$

where, again σ_{11} is Cauchy stress.

Assuming incompressibility:

$$\lambda_1 \lambda_2 \lambda_3 = 1 \tag{158}$$

and noting that:

$$\lambda_2 = \lambda_3 \tag{159}$$

the deformation invariant becomes

$$\sqrt{II_{B'}} = \frac{1}{\sqrt{3}}(\lambda_1^2 - \frac{1}{\lambda_1}) \tag{160}$$

Taking the rate of change of this invariant as being approximately constant results in:

$$f = \sqrt{3}\,\dot{\lambda} \int_0^t G(t - \tau)\, d\tau \tag{161}$$

so that, from equations (155), (158), and (160), the following is obtained:

$$\frac{\sigma_{11}}{\sqrt{3}} = g \sqrt{3}\,\dot{\lambda} \int_0^t G(t - \tau)\, d\tau \tag{162}$$

from which the softening function, g, may be obtained. The assumption leading to equation (160), that the time-rate of change of $\sqrt{II_{B'}}$ is approximately constant, need be guarded against for conditions of changing strain rate. For example, as in dual-rate tests where viscoelasticity does not predict as fast a response to the rate change as is experimentally observed.

The modification to linear viscoelasticity necessary to accommodate this behavior is as follows. The response of the function f in equation (163) to a constant time rate of change of the deformation invariant is defined as f_c. It can be expressed as:

$$f_c = \sqrt{\dot{II}_{B'}} \int_0^{\xi} G_{rel} (\xi - \tau)\, d\tau \tag{163}$$

$$\text{where } \xi = \sqrt{II_{B'}} \,/\, \sqrt{\dot{II}_{B'}}$$

The modification to the f function is done in an incremental manner through:

$$\dot{f}_{modified} = \dot{f} + \beta \left[f_c - f \right] \sqrt{\dot{II}_{B'}} \tag{164}$$

and the following incremental relationship is used:

$$f \Big|_{t + dt} = f \Big|_{t} + \frac{df_{mod}}{dt}\, dt \tag{165}$$

The parameter β governs the response of the f function under changing strain rates. As $\beta > 0$, the response is analogous to linear viscoelasticity.

The algorithm developed by Herrman and Peterson (Reference 30) has been used to implement the calculation of the convolution integral for f. In brief, let the shear relaxation modulus be represented by a Prony series as

$$G(t) = \sum_{i=1}^{m} G_i e^{-\sigma_i t} \tag{166}$$

Then let the f function at time t_n be given by:

$$f(t_n) = \int_0^{t_n} \sum_i G_i e^{-\alpha_i (t_n - \tau)} \frac{\partial \sqrt{II_{B'}}}{\partial \tau}\, d\tau \tag{167}$$

A recursion relation can be easily developed to compute $f(t_n)$ (Reference 30). Let

$$f\,(t_n) = \sum_{i=1}^{m} I_{n,i} \tag{168}$$

and

$$I_{n,i} \equiv \int_{0}^{t_n} G_i e^{-\alpha_i (t_n - \tau)} \frac{\partial \sqrt{II_{B'}}}{\partial \tau} \, d\tau \tag{169}$$

then

$$I_{n,i} = e^{-\alpha_i \Delta t_n} I_{n-1,i} + \sqrt{\dot{II}_{B'_n}} \frac{G_i}{\alpha_i} \left[1 - e^{-\alpha_i \Delta t_n} \right] \tag{170}$$

giving for the change in these terms

$$\Delta I_{n,i} = \sqrt{\dot{II}\ B'_n} \left\{ \frac{G_i}{\alpha_i} \left[1 - e^{-\alpha_i \Delta t_n} \right] + I_{n-1,i} + \left[e^{-\alpha_i t_n} - 1 \right] \right\} \tag{171}$$

which is directly analogous to linear viscoelasticity. The modification proposed above can then be implemented as

$$(\Delta I_{n,i})_{\text{modified}} = \Delta I_{n,i} + \beta \left[I_{cn,i} - I_{n,i} \right] \Delta \sqrt{II_{B'}} \tag{172}$$

and the I terms can be incremented according to:

$$I_{n,i} = I_{n-1,i} + (\Delta I_{n,i})_{modified} \tag{173}$$

This has the effect of changing each term of the series so that it approaches the value it would have been if it was always at the new strain rate. Note again that (as discussed in Reference 30) varying temperatures can be incorporated into the time scale as usual.

Unloading tests required a further refinement of the model. For lack of more detailed information, the parameter β may be taken as zero for unloading states (i.e., states in which $\sqrt{II_B'}$ is decreasing). The large amount of hysteresis seen in load-unload cycles is then modeled in part by the hysteresis inherent in linear viscoelasticity primarily through the g function. This is accommplished by giving g a different value when the deformation invariant $\sqrt{II_B'}$ is less than its maximum previously achieved during the loading history. If $\sqrt{II_B'}_{max}$ is the current maximum value, the function:

$$g = g(\sqrt{II_{B'\,max}}) \left\{ 1 - C_1 \left[1 - \sqrt{II_{B'}} / \sqrt{II_{B'\,max}} \right] \right\} \tag{174}$$

provides plasticity-like behavior.

The behavior of the g function for unloading and reloading conditions is illustrated in Figure 120 (taken from Reference 9).

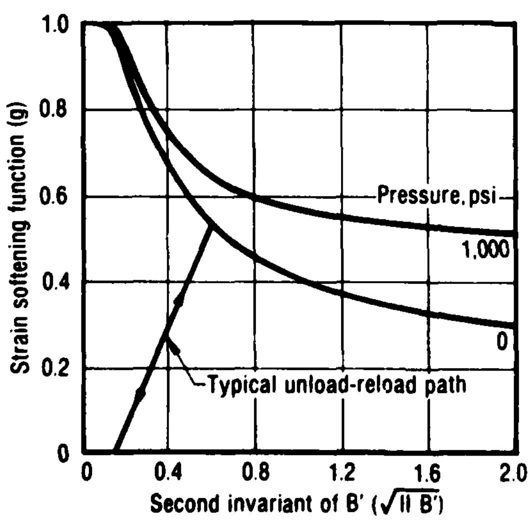


Figure 120. Effect of Deformation and Pressure on the Strain Softening Function 22059

The Swanson approach (Reference 9) was used with an only limited degree of success to predict the stress response of TP-H1011 and UTP-19,360B under several strain histories.

In the case of TP-H1011, the errors in the predictions were believed to be due to uncertainties in the value of the changing-rate coefficient (β). There was no data available to determine β directly for this propellant.

It was possible to characterize UTP-19,360B in a complete fashion. The corresponding predictions were not any better than those obtained for TP-H1011. This led to changing the law as discussed below.

4.2.6.2 Current Model

Analysis of the stress predictions, carried out for UTP-19,360B with the original Swanson theory, revealed the importance of several inadequacies and oversimplifications listed below.

1. The softening function (g) should depend not only on the strain and pressure but also on the strain rate.
2. The softening function, as defined by equations (155) and (163), should be different for unloading than for reloading.
3. The softening function for unloading or for reloading should never become zero for conditions of tensile straining only. A zero value could occur with the softening function defined by equation (174).
4. The healing process observed during relaxation in solid propellants like UTP-19,360B was not taken into consideration by the original Swanson theory.
5. The reverse-recovery observed in solid propellants during relaxation or rest periods that follow an unloading process, only poorly modeled by classical viscoelasticity, is not considered in the approach by Swanson.
6. The changing-rate coefficient (β) is more a mathematical device than it is a material property. If the softening function is made to depend on the strain rate then β need not be used.
7. The use of a softening function as a stress correction factor eliminates the need of using the Cauchy stress (σ) and the nonlinear measure of stretching (B).

All these observations were incorporated into the original stress-strain law but the general form of the corresponding equations remained the same, namely;

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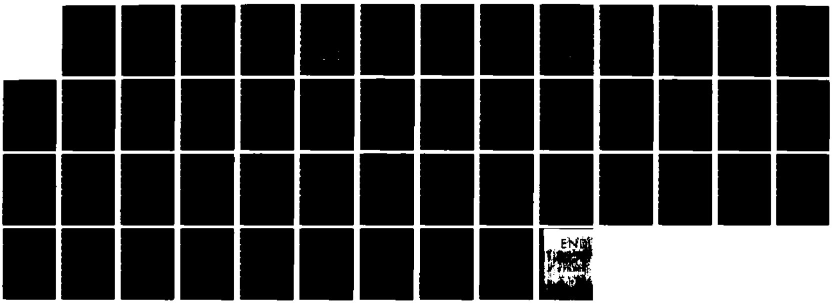
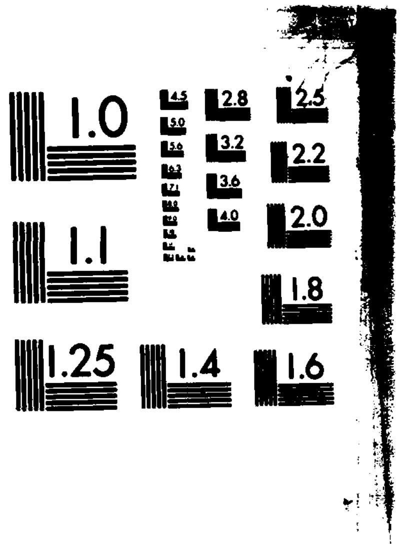




MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

$$\sigma_{11} = \sqrt{3}\,(g) \int_{o}^{t} G\,(s_t - s_\tau)\,\frac{\partial\sqrt{II_{B'}}}{\partial \tau}\,d\tau \qquad (175)$$

valid for one-dimensional loading, with:

$$s_t - s_\tau = \int_{\tau}^{t} \frac{d\xi}{a_T\left[\pi(\xi)\right]} \qquad (176)$$

representing temperature-reduced time; and where the time-temperature shift function was taken in the power-law form:

$$a_T = \left(\frac{T_R - T_a}{T - T_a}\right)^m \qquad (177)$$

in which T_R is the shift reference temperature, T_a and m are material parameters, and T is the current temperature.

The modified version of the Swanson theory was most successfully used to predict the response of UTP-19,360B, as explained next.

4.2.6.3 Stress Predictions

The degree of accuracy of the predictions made with the current version of the Swanson approach may be realized by examining Figures 121 through 130. The first two figures correspond to the lowest and highest constant-rate tests available. Figure 123 shows the predictions corresponding to a saw-tooth test at constant rate and increasing peak strains. Figures 124 and 125 present the results for the dual-rate tests while Figures 126 and 128 pertain to the long- and short-duration similitude tests, respectively. Figure 127 shows the three-step relaxation test. Finally, Figures 129 and 130 show the results obtained for constant rate tests at 123°F and 40°F.

(Text continued on page 285.)

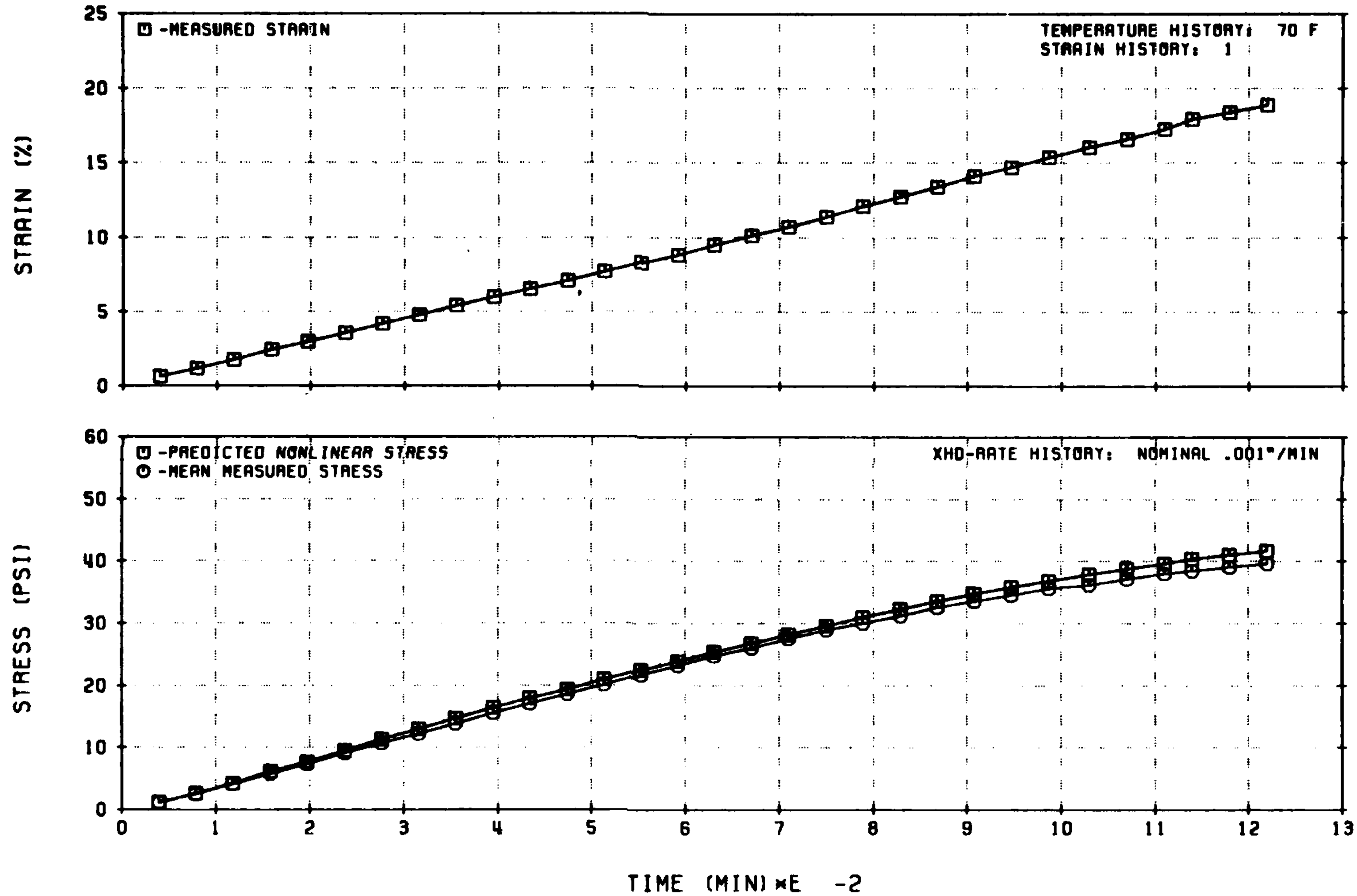


Figure 121. Nonlinear Viscoelastic Stress Predictions for Constant-Rate Test (UTP-19,360B-400/1777)

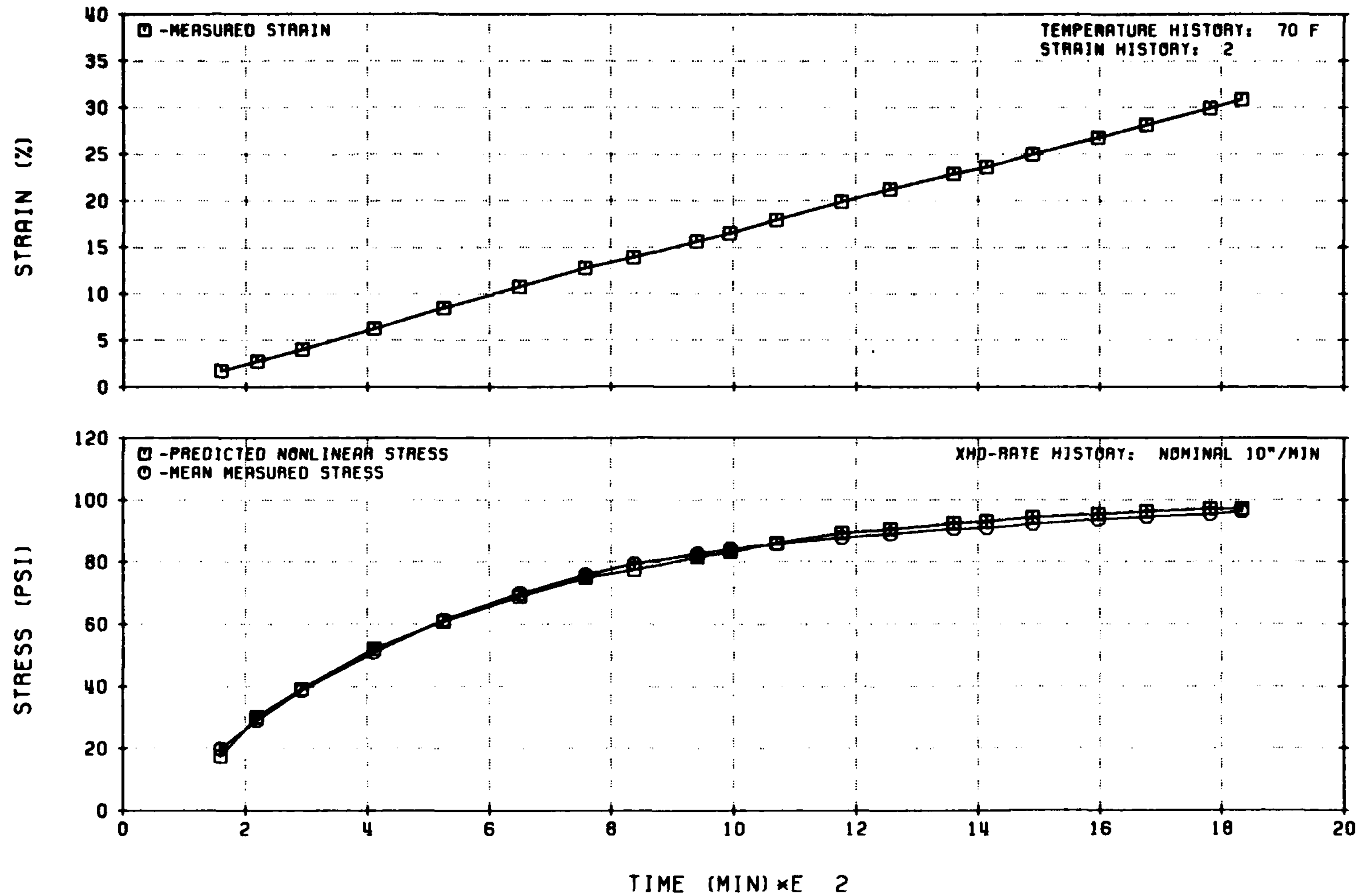


Figure 122. Nonlinear Viscoelastic Stress Predictions for Constant-Rate Test (UTP-19,360B-400/1777)

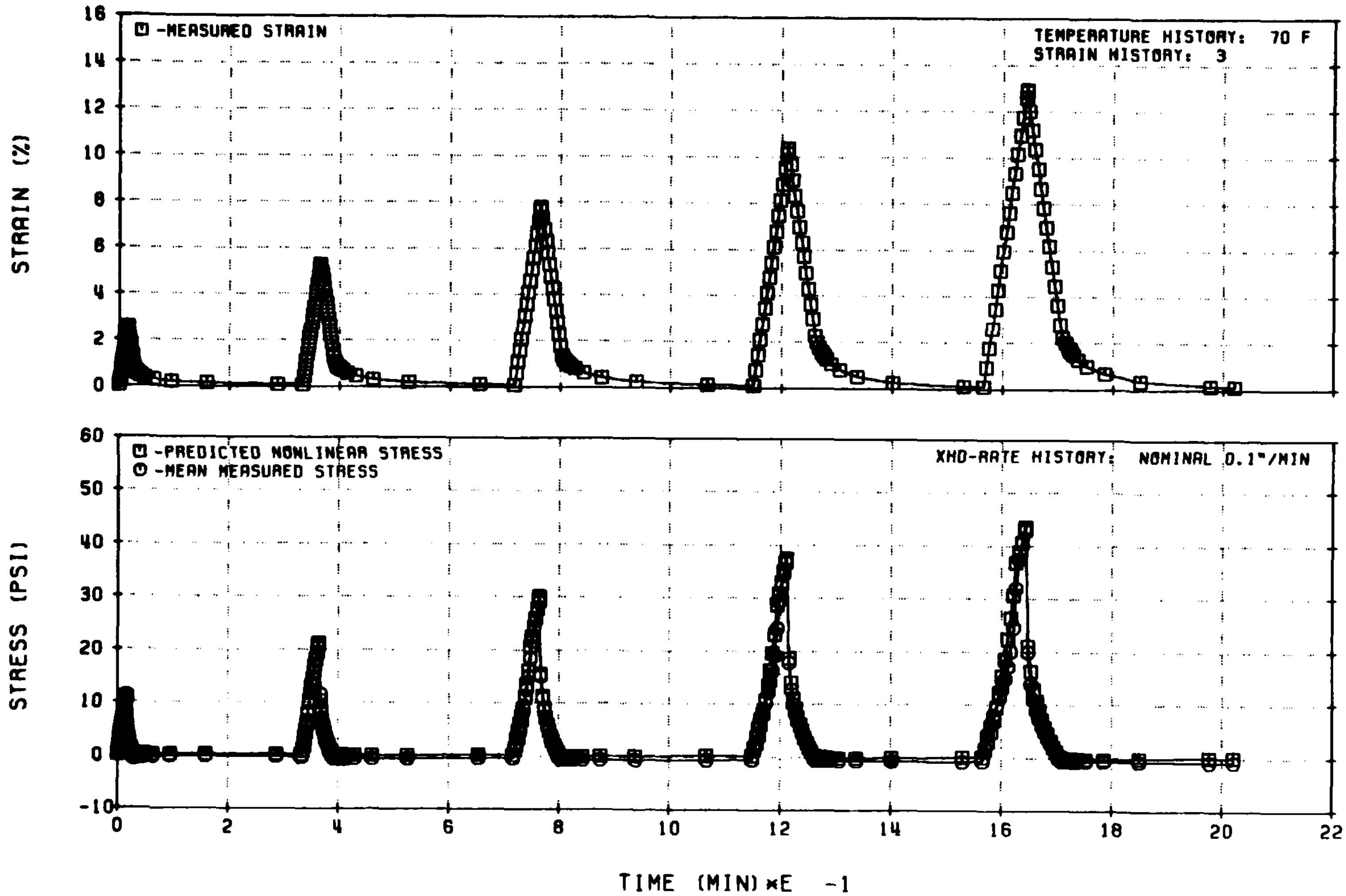


Figure 123. Nonlinear Viscoelastic Stress Predictions for Saw-Tooth Test (UTP-19,360B-400/1777)

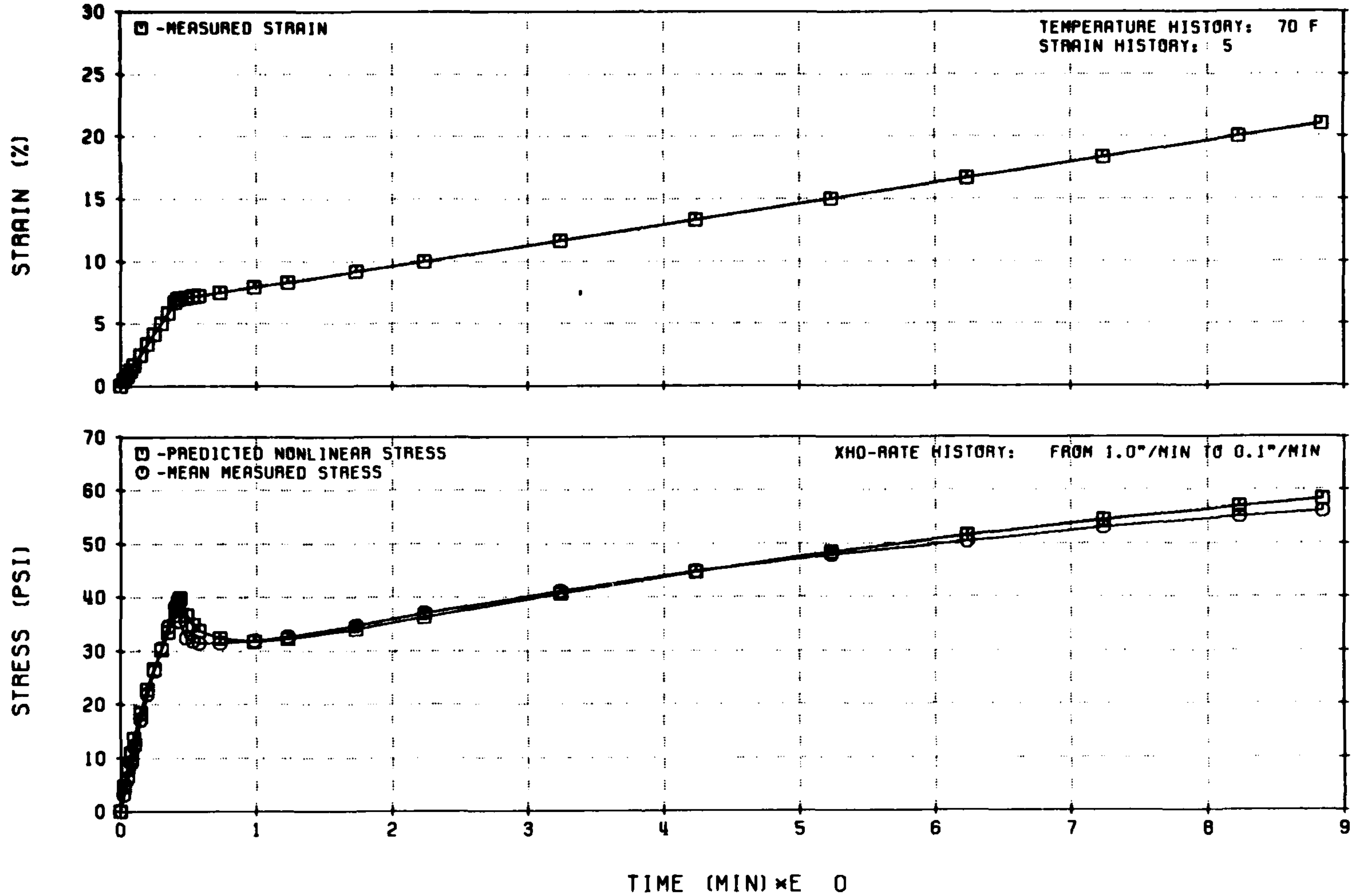


Figure 124. Nonlinear Viscoelastic Stress Predictions for Two-Rate Test (UTP-19,360B-400/1777)

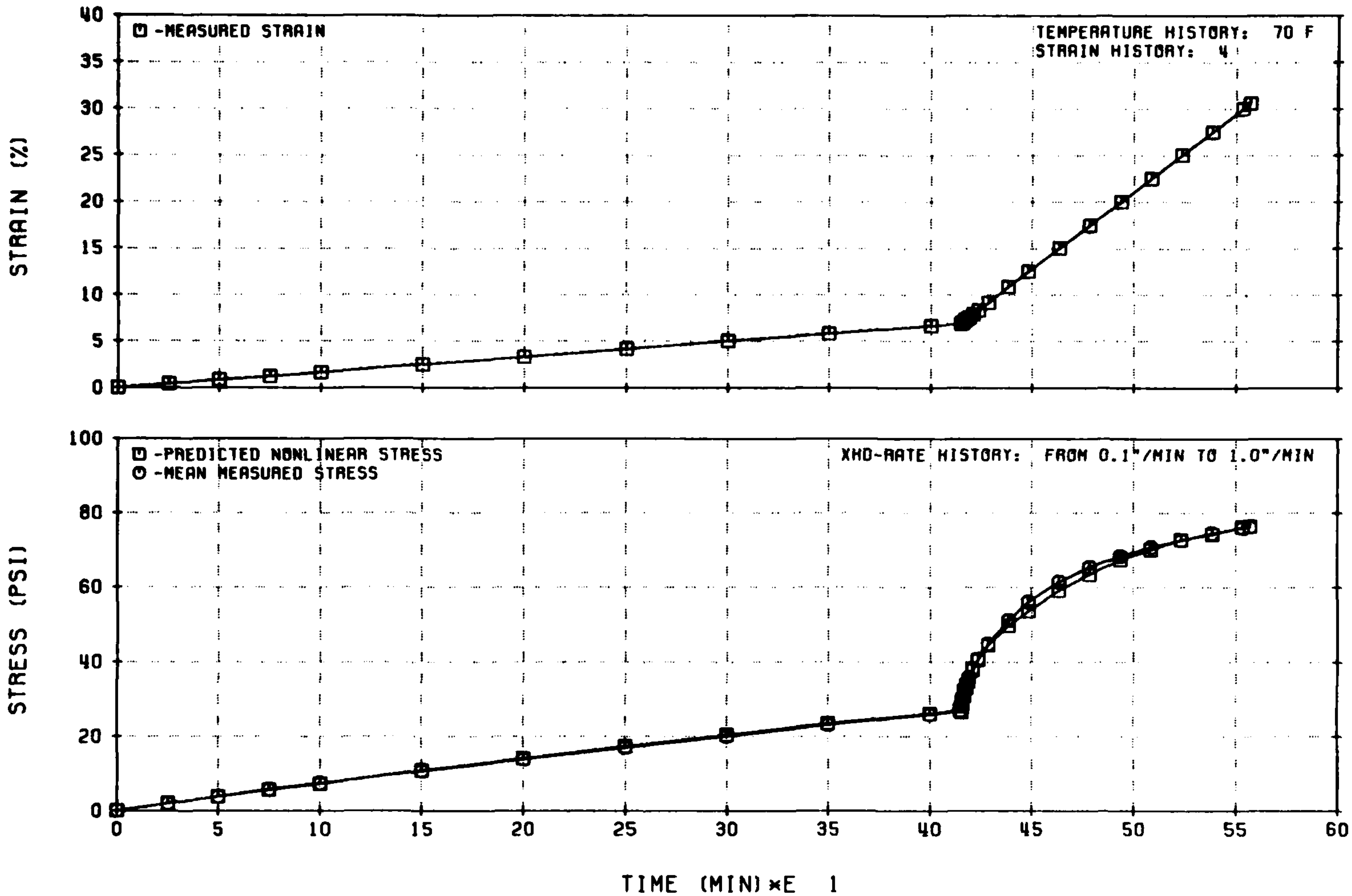


Figure 125. Nonlinear Viscoelastic Stress Predictions for Two-Rate Test (UTP-19,360B-400/1777)

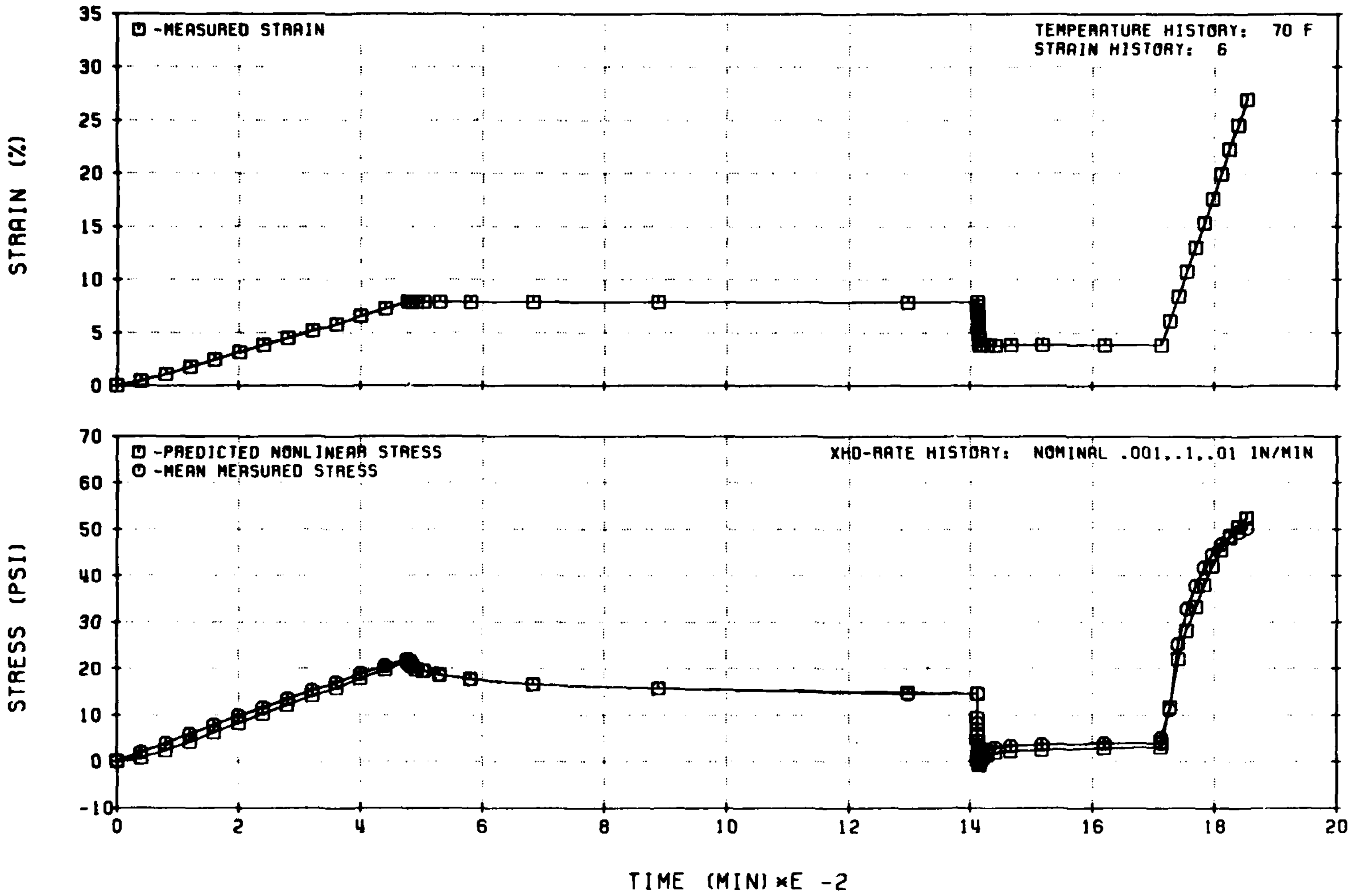


Figure 126. Nonlinear Viscoelastic Stress Predictions for Long Similitude Test
(UTP-19,360B-400/1777)

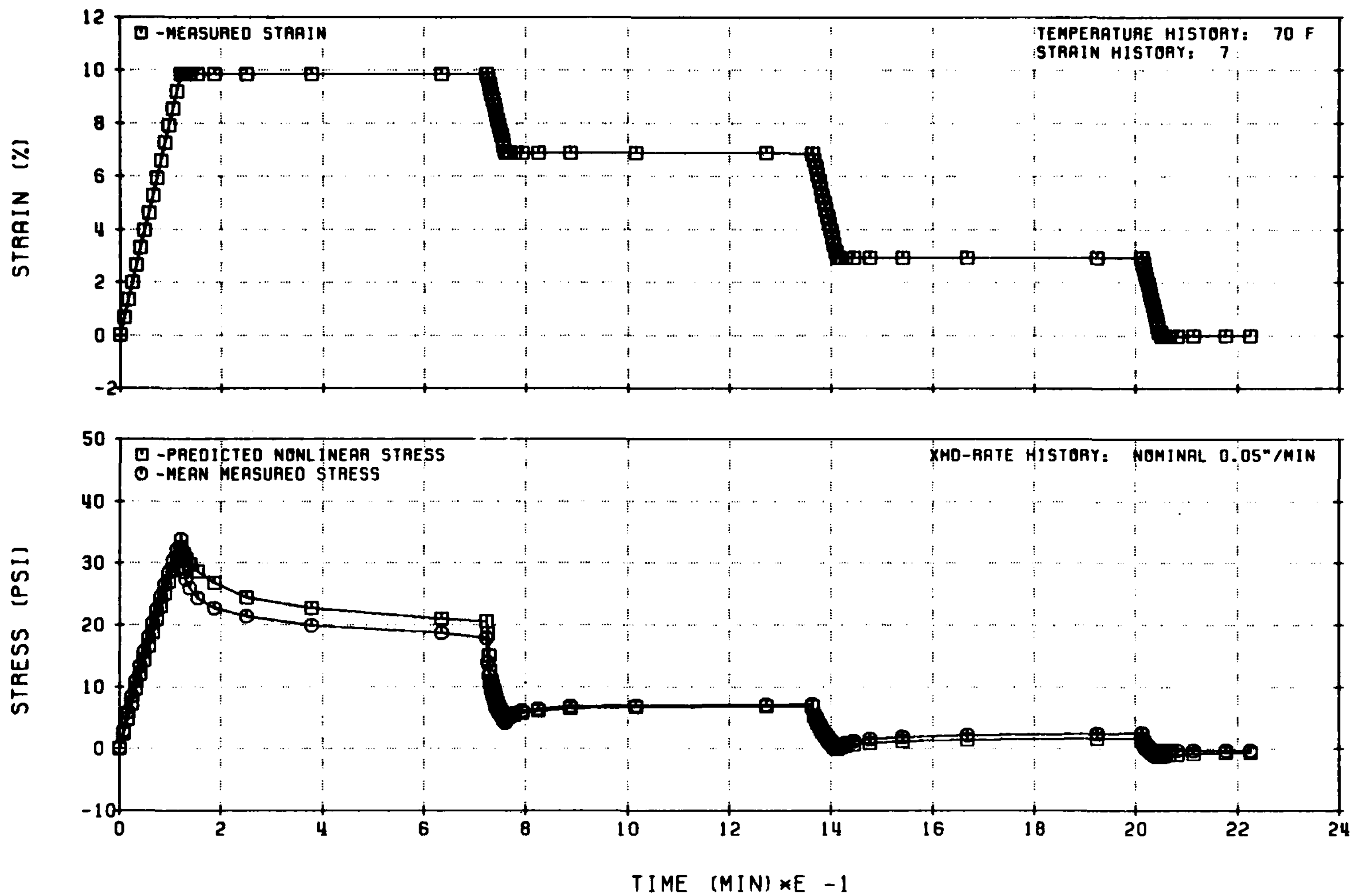


Figure 127. Nonlinear Viscoelastic Stress Predictions for 3-Step Relaxation (UTP-19,360B-400/1777)

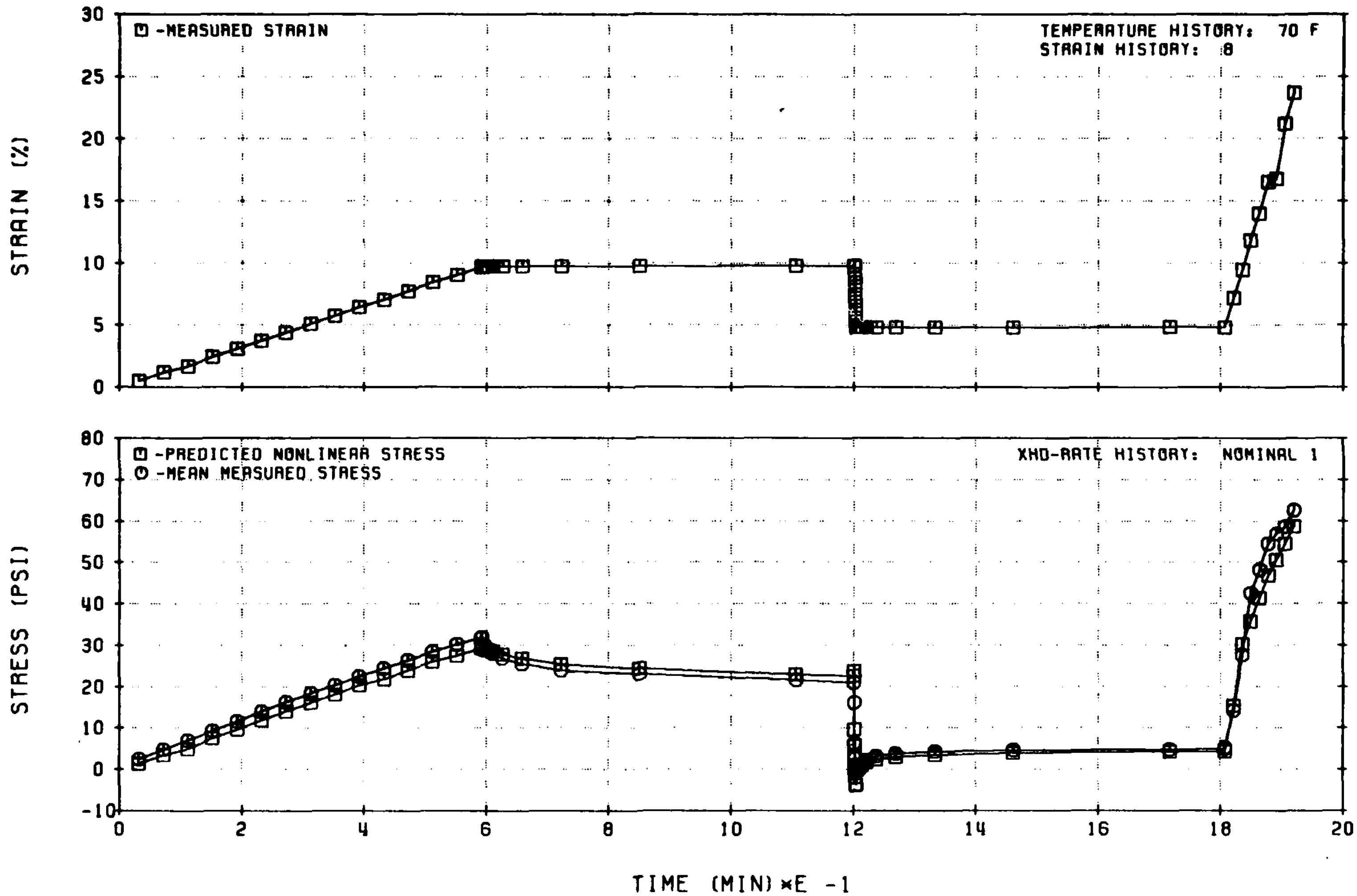


Figure 128. Nonlinear Viscoelastic Stress Predictions for Short Similitude Test (UTP-19,360B-400/1777)

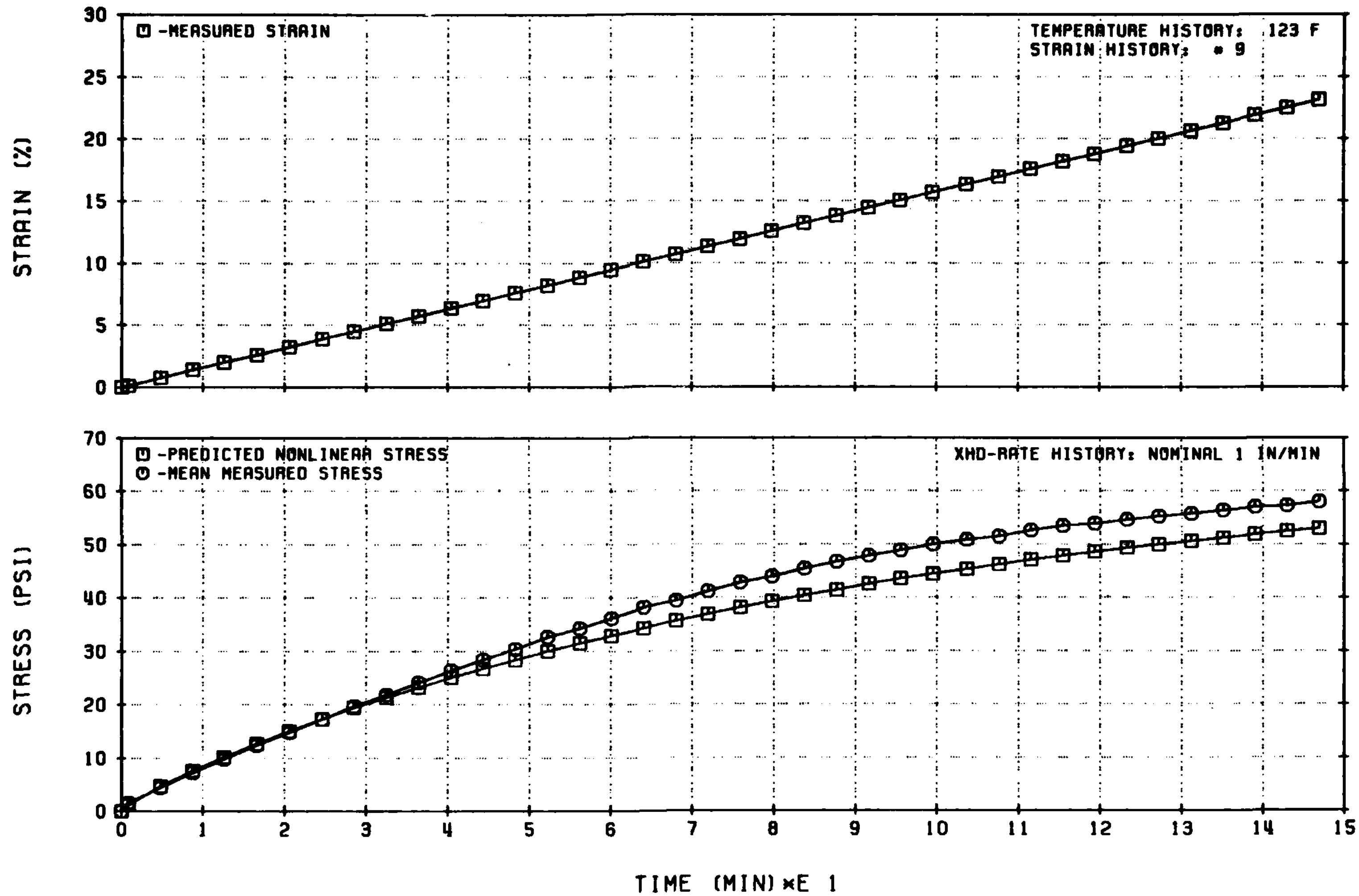


Figure 129. Nonlinear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 at 123 F

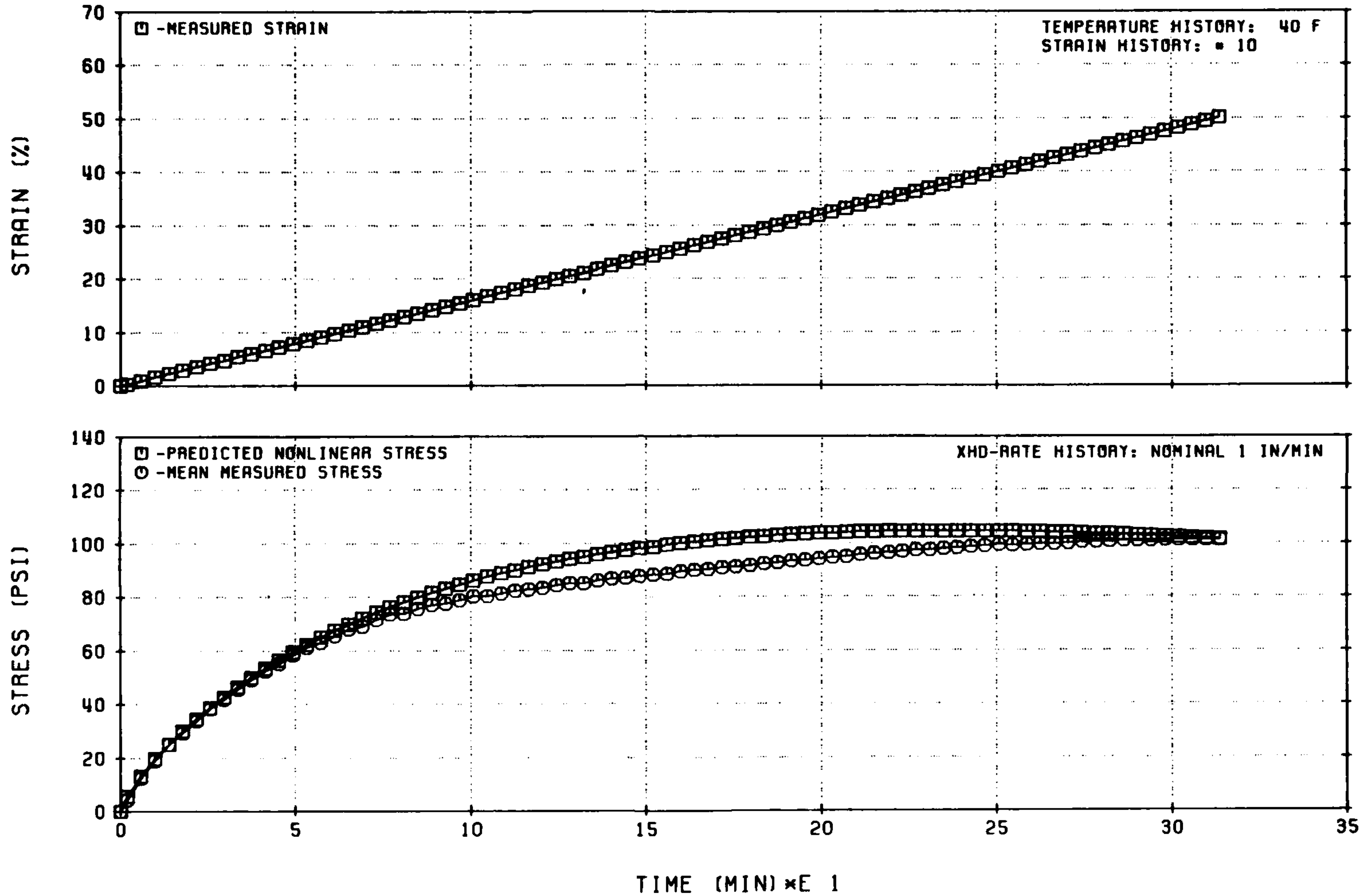


Figure 130. Nonlinear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 at 40 F

They testify to the fact that the time-temperature superimposition principal may be used without sacrificing more accuracy than is already lost in fitting equation (143) to the very limited time-temperature shift data.

4.2.6.4 Material Characterization

According to this theory, only the following listed properties are needed to characterize a solid propellant completely:

1. The relaxation function, G, defined as:

$$G(t) = \frac{E_{rel}(t)}{3} \tag{178}$$

where $E_{rel}(t)$ is the linear viscoelastic relaxation modulus.

2. The softening function, g, defined and obtained as follows:

a. For loading conditions:

$$g_L = g(\epsilon, \dot{\epsilon}) \tag{179}$$

and it is obtained from a sequence of constant-rate tests at at least three different rates that span the range expected in the applications.

b. For unloading conditions:

$$g_u = g(\epsilon/\epsilon_{max}) \tag{180}$$

where ϵ_{max} represents the maximum strain previously achieved during the loading history. The g is determined from the unloading portion of a loading-unloading cycle carried up to an intermediate strain level.

c. For relaxation conditions:

$$g_r = g_r\ (t - t_o) \tag{181}$$

in which t_o is the time at which the relaxation process begins and g is evaluated from a relaxation test at an intermediate strain level.

In addition, for relaxation after partial unloading or during rest periods starting at $t = t_o$:

$$\hat{g}_r = \frac{1}{g_r\ (t - t_o)} \tag{182}$$

Also, the stress-correction function for reloading is taken as a linear function of the relative strain. It is a straight line from the point where reloading starts to the point of maximum loading over the past history.

4.2.6.5 Addendum to Swanson Theory

Three-Dimensional Version of the Model

The (general) constitutive assumption used to relate the deviatoric components of the stress and deformation tensors, takes the following form:

$$\frac{\sigma'_{ij}}{\sqrt{II_{\sigma'}}} = \frac{B'_{ij}}{\sqrt{II_{B'}}};\ i,\ j = 1,\ 2,\ 3 \tag{183}$$

together with:

$$\sqrt{II_{\sigma'}} = (g)\ (f) \tag{184}$$

or, equivalently:

$$\sqrt{II_{\sigma'}} = (g) \int_0^t G(t-\tau) \frac{\partial \sqrt{II_{B'}}}{\partial \tau} d\tau \tag{185}$$

where:

σ'_{ij} = i-j component of the deviatoric Cauchy stress tensor

B'_{ij} = i-j component of the deviatoric Left Cauchy-Green deformation tensor

II_{σ}, II'_{B}, = second invariants of the deviatoric stress and deformation tensors

with:

$$\sigma'_{ij} = \sigma_{ij} + \frac{1}{3}(\sigma_{11} + \sigma_{22} + \sigma_{33})\delta_{ij};\ i,\ j = 1,\ 2,\ 3 \tag{186}$$

$$II_{\sigma'} \overset{\text{def}}{=} \left\{ -\left[\sigma_{11}\,\sigma'_{22} + \sigma'_{11}\,\sigma'_{33} + \sigma'_{22}\,\sigma'_{33}\right] + (\sigma'_{12})^2 + (\sigma'_{13})^2 + (\sigma'_{23})^2 \right\} \tag{187}$$

and similarly for B'_{ij} and II_{B}'; and in which:

$$\delta_{ij} \overset{\text{def}}{=} \begin{cases} 1 \text{ for } i = j \\ 0 \text{ for } i \neq j \end{cases} \tag{188}$$

also:

g = softening function that depends primarily on the strain level, the strain rate, and the applied pressure.

and:

$$G(t) \overset{\text{def}}{=} E(t)/3 \tag{189}$$

where E(t) represents the tensile relaxation modulus at a small strain.

According to the constitutive assumptions (183) and (185), the distortional behavior of the material is completely characterized through the softening function, g, and the relaxation function, G, which may be evaluated from one-dimensional tests, as explained in the previous section. Indeed, the stress-strain relations set forth in equation, (183) and (185), reduce, as they should, to those employed in the one-dimensional version of the model.

To complete the theory, an assumption is still needed about volumetric behavior; and although time-dependent bulk response may be important in some applications, the elastic relation:

$$\frac{1}{3}(\sigma_{11} + \sigma_{22} + \sigma_{33}) = K\,(|\lambda_1 \lambda_2 \lambda_3| - 1) \qquad (190)$$

may be employed; in which K is the bulk modulus and the λ_i's are the stretch ratios.

For an incompressible material (and solid propellants are nearly incompressible):

$$\lambda_1 \lambda_2 \lambda_3 = 1 \qquad (191)$$

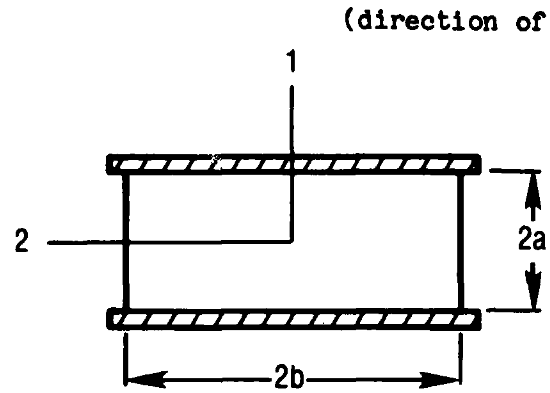
so that equation (190) breaks down, and the stress tensor has to be considered a function of the mean pressure $(\sigma_{11} + \sigma_{22} + \sigma_{33})/3$, as well as of the deformation tensor, leading eventually, to a stress-strain law of the form given in equation (183).

Application of the Model to Two-Dimensional Problems

In order to use the stress-strain law presented in the foregoing section, one must have available the deformation tensor at each point of the continuum where the stresses are desired. This solution in terms of deformation may be arrived at numerically through, say, finite elements, or, analytically.

The accuracy with which the present constitutive theory may predict the two-dimensional response of solid propellants may be seen in Figures 131 to

136, which correspond to constant strain-rate tests of strip-biaxial samples of UTP-19,360B. The first three figures belong to tests performed at a nominal crosshead displacement rate of 0.02 in./min. at 40°F, 70°F, and 120°F, respectively; while Figures 134 to 136 show the results for a crosshead displacement rate of 0.2 in./min. at the same low, intermediate and high temperatures of 40°, 70°, and 120°F. The plotted data refer to the direction of applied loading, which is also the direction of maximum principal stress (and strain). The geometry of the strip-biaxial sample used is as presented in the following sketch.



$$a/b = 1.25/6 \doteq 4.8$$

$$\sigma_{22}/\sigma_{11} \equiv \phi_\sigma \doteq 0.481 \qquad (192)$$

$$\epsilon_{22}/\epsilon_{11} \equiv \phi_\epsilon \doteq 0.025$$

The stress- and strain-axiality factors, ϕ_σ and ϕ_ϵ , were taken from Reference (31), and are valid at the center of the sample <u>for small strains only</u>.

The constitutive relations given in (183) and (185) yield:

$$\sigma'_{ij} = (g)\frac{B'_{ij}}{\sqrt{II_{B'}}} \int_0^t G(t - \tau)\, \frac{\partial\sqrt{II_{B'}}}{\partial \tau}\, d\tau \qquad (193)$$

where:

$$\frac{\partial\sqrt{II_{B'}}}{\partial t} = \frac{\partial\sqrt{II_{B'}}}{\partial B'_{ij}}\, \frac{\partial B'_{ij}}{\partial t};\; i,\, j = 1,\, 2,\, 3 \qquad (194)$$

with summation implied over repeated indices.

Now, under conditions of plane stress of an incompressible material, and along the principal directions, one has:

$$\left[\sigma'_{ij}\right] = \frac{1}{3}\begin{bmatrix} (2\sigma_1 - \sigma_2) & 0 & 0 \\ 0 & (2\sigma_2 - \sigma_1) & 0 \\ 0 & 0 & -(\sigma_1 + \sigma_2) \end{bmatrix} \tag{195}$$

$$\left[B'_{ij}\right] = \frac{1}{3}\begin{bmatrix} (2\lambda_1^2 - \lambda_2^2 - \lambda_3^2 & 0 & 0 \\ 0 & (2\lambda_2^2 - \lambda_3^2 - \lambda_1^2 & 0 \\ 0 & 0 & (2\lambda_3^2 - \lambda_1^2 - \lambda_2^2) \end{bmatrix} \tag{196}$$

$$II_{B'} = -B'_{11}\,B'_{22} - B'_{11}\,B'_{33} - B'_{22}\,B'_{33} \tag{197}$$

To evaluate (194), we first write it in unabridged notation, noting that in this case, if $i \neq j$ then $B'_{ij} = 0$; thus:

$$\frac{\partial\sqrt{II_{B'}}}{\partial t} = \frac{\partial\sqrt{II_{B'}}}{\partial B'_{11}}\frac{\partial B'_{11}}{\partial t} + \frac{\partial\sqrt{II_{B'}}}{\partial B'_{22}}\frac{\partial B'_{22}}{\partial t} + \frac{\partial\sqrt{II_{B'}}}{\partial B'_{33}}\frac{\partial B'_{33}}{\partial t} \tag{198}$$

and using (197):

$$\frac{\partial\sqrt{II_{B'}}}{\partial t} = \frac{1}{2\sqrt{II_{B'}}}\left[(-B'_{22} + B_{33})\frac{\partial B'_{ij}}{\partial t} + (-B'_{33} - B'_{11})\frac{\partial B'_{22}}{\partial t} + \right.$$
$$\left. + (-B'_{11} - B'_{22})\frac{\partial B'_{33}}{\partial t}\right] \tag{199}$$

where, from (196) one has, for instance, that:

$$\frac{\partial B'_{11}}{\partial t} = \frac{2}{3}\left(2\lambda_1 \frac{d\lambda_1}{dt} - \lambda_2 \frac{d\lambda_2}{dt} - \lambda_3 \frac{d\lambda_3}{dt}\right) \tag{200}$$

and similarly for the derivatives of B'_{22} and B'_{33}.

In the previous derivations, the stretch ratios are computed as:

$$\begin{aligned} \lambda_1 &= 1 + \epsilon_1 (t) \\ \lambda_2 &= 1 + \epsilon_2 (t) \doteq 1 + \phi_\epsilon \epsilon_1 (t) \\ \lambda_3 &= 1/(\lambda_1\lambda_2) \end{aligned} \tag{201}$$

in which $\epsilon_1(t)$ is the strain history imposed on the sample along coordinate 1, and the last expression of (201) follows from the incompressibility condition, equation (191).

Hence, the first component-equation of the constitutive relation (193) yields:

$$\sigma'_{11} \equiv \frac{1}{3}(2\sigma_1 - \sigma_2) = (g)\frac{B'_{11}}{\sqrt{II_{B'}}} \int_0^t G(t-\tau) \frac{\partial\sqrt{II_B}}{\partial\tau} d\tau$$

or, in view of (192):

$$\sigma_1 \frac{(2 - \phi_\sigma)}{3} = (g)\frac{B'_{11}}{\sqrt{II_{B'}}} \int_0^t G(t-\tau) \frac{\partial\sqrt{II_{B'}}}{\partial\tau} d\tau$$

and finally:

$$\sigma_1 = \frac{3}{(2 - \phi_\sigma)} (g)\frac{B'_{11}}{\sqrt{II_{B'}}} \int_0^t G(t-\tau) \frac{\partial\sqrt{II_{B'}}}{\partial\tau} d\tau \tag{202}$$

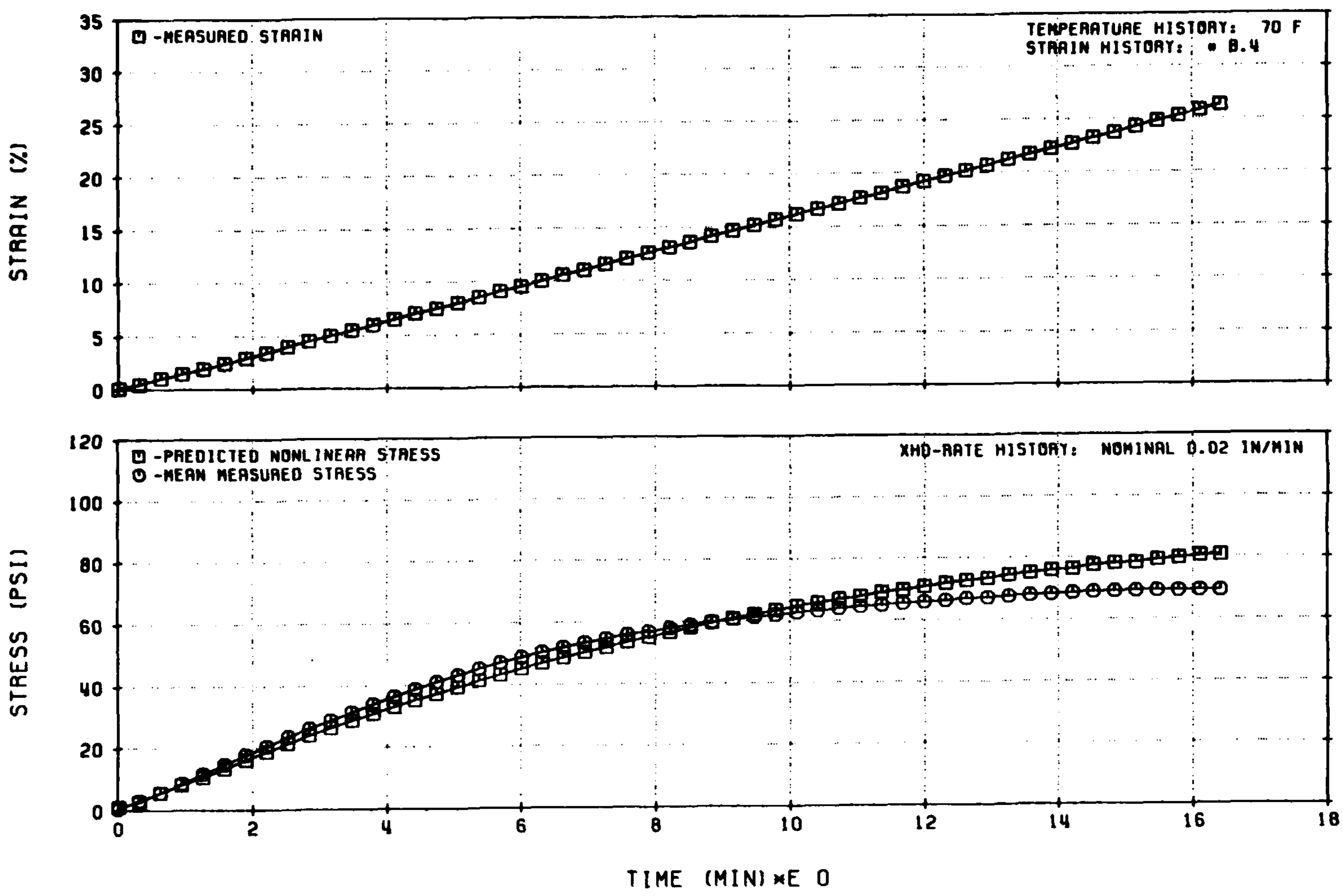


Figure 131. Nonlinear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 (Biaxial Sample) Hercules Theory

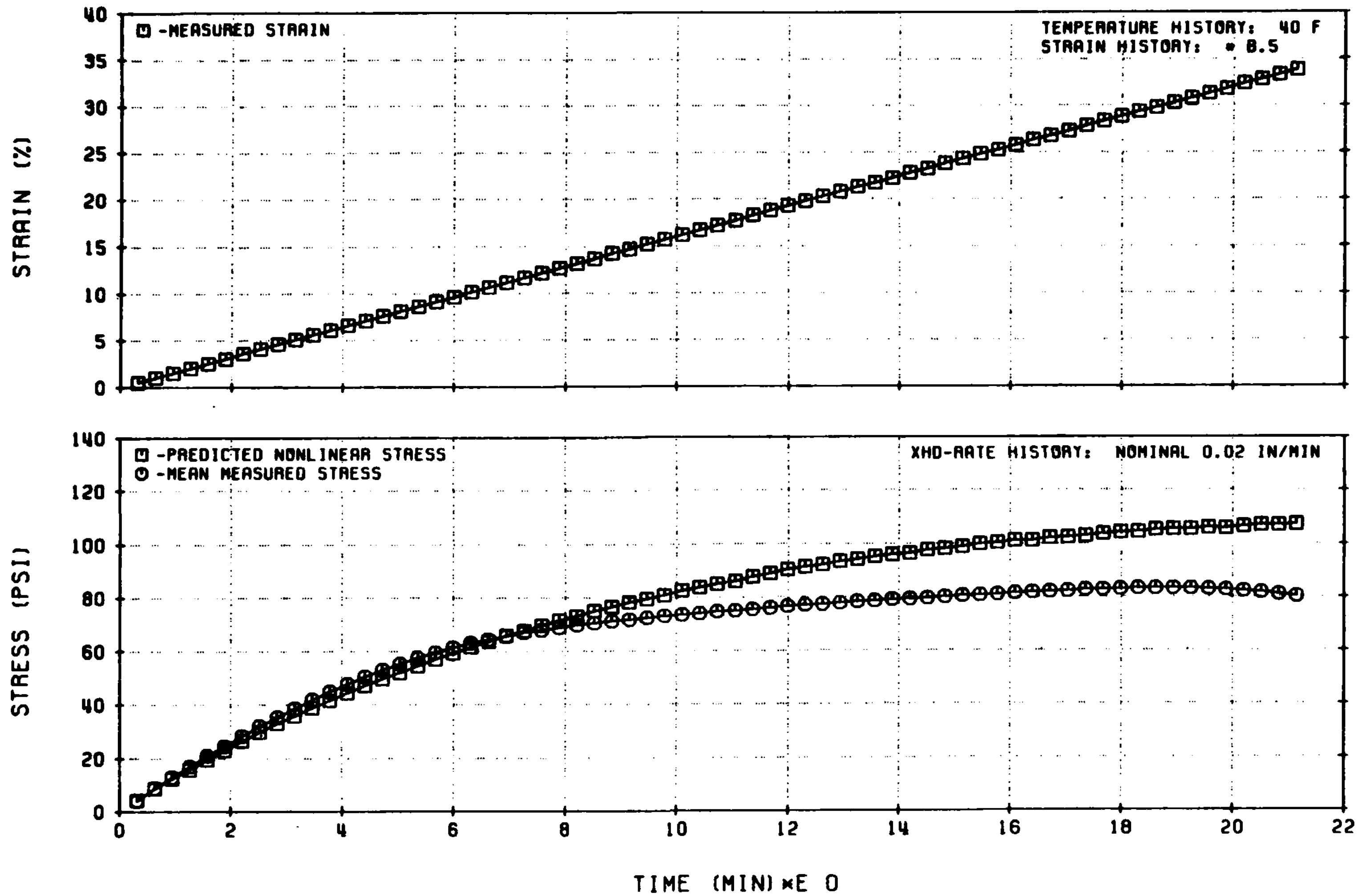


Figure 132. Nonlinear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 (Biaxial Sample) Hercules Theory

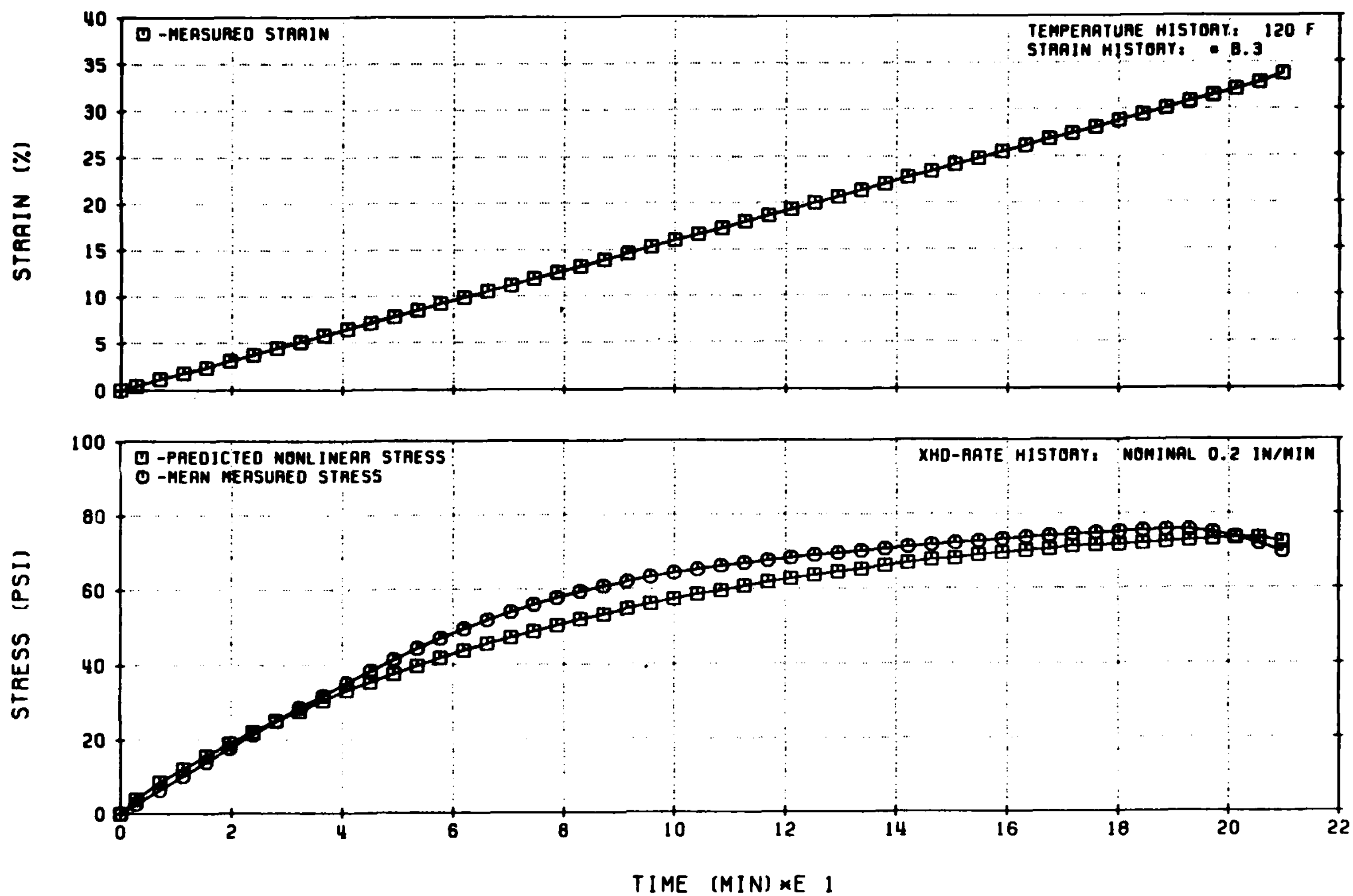


Figure 133. Nonlinear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 (Biaxial Sample) Hercules Theory

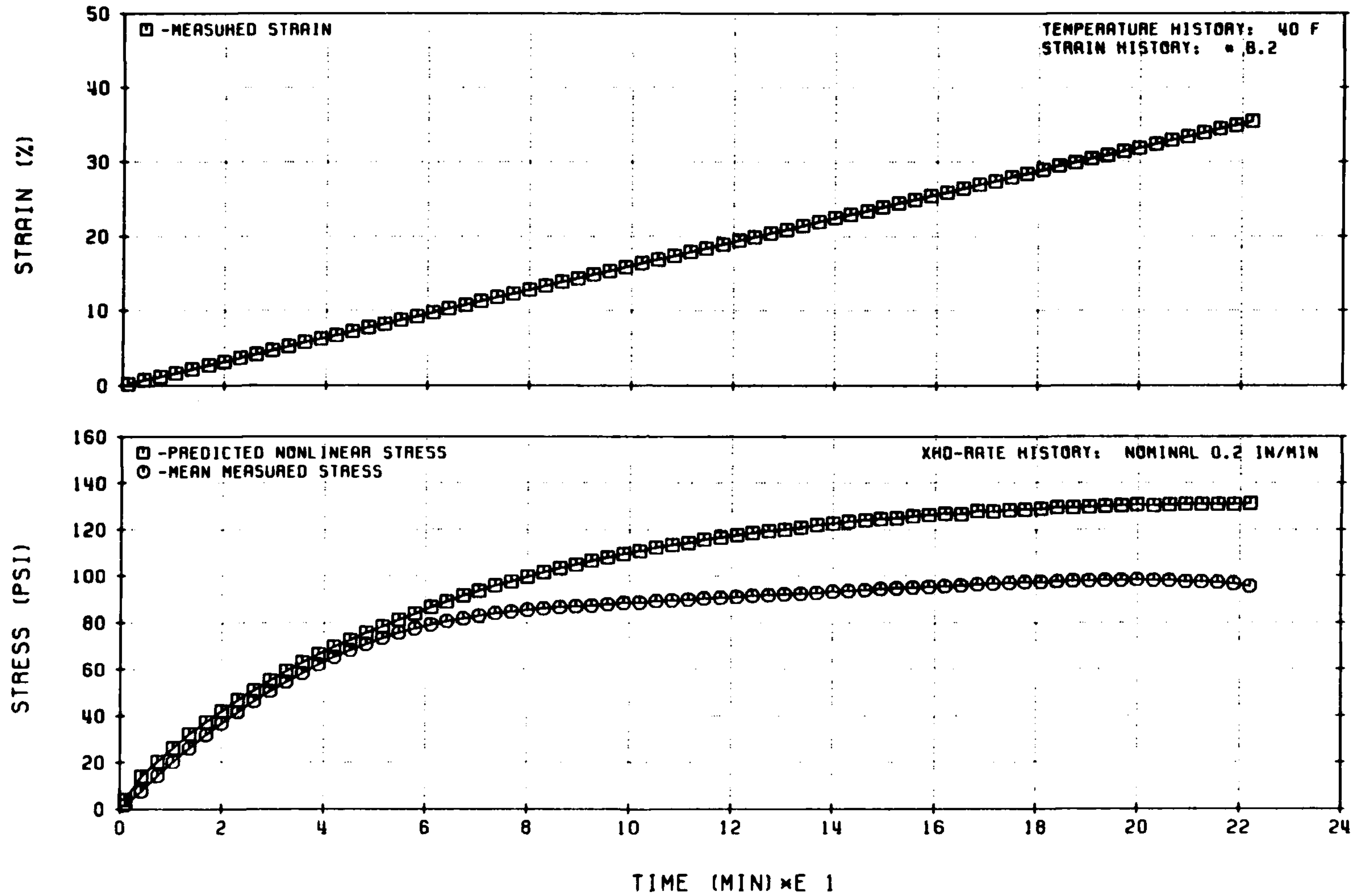


Figure 134. Nonlinear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 (Biaxial Sample) Hercules Theory

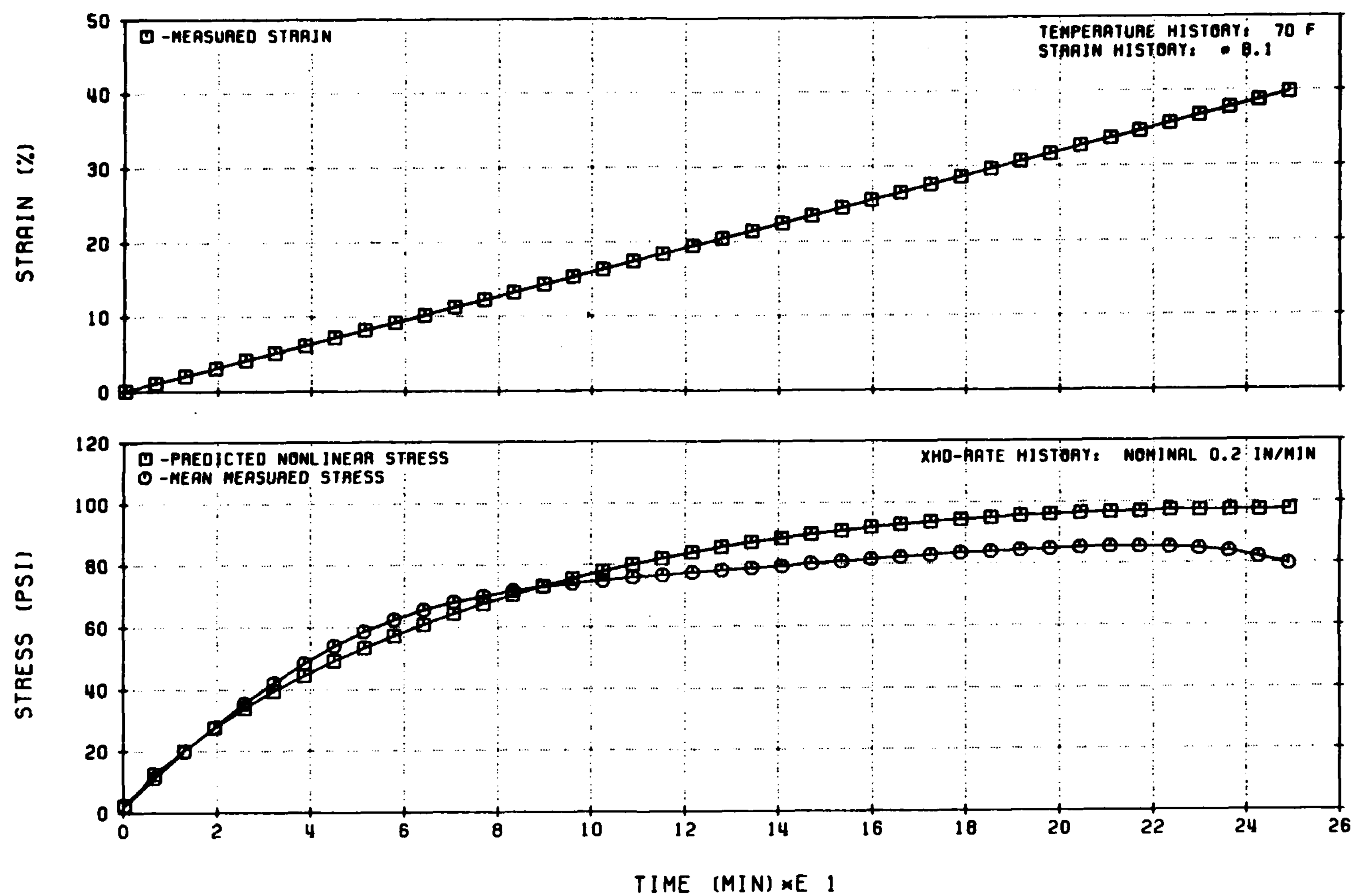


Figure 135. Nonlinear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 (Biaxial Sample) Hercules Theory

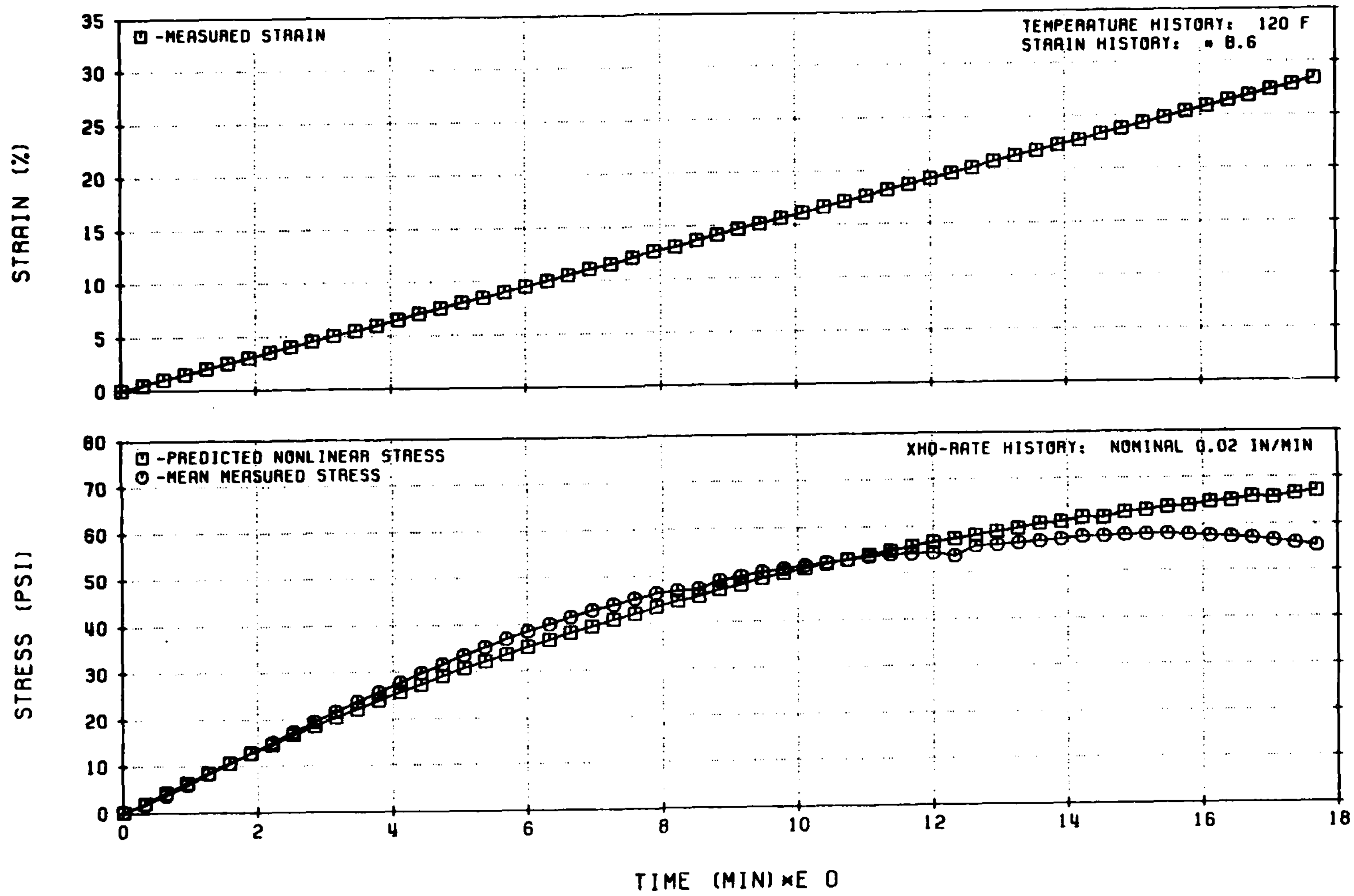


Figure 136. Nonlinear Viscoelastic Stress Predictions for UTP-19,360B-400/1777 (Biaxial Sample) Hercules Theory

Using equations (192), (196), and (199) to (202), we obtained the response of the biaxial sample in the direction of the applied loading. The plots included in this report, show the engineering stress:

$$\sigma_1 = \sigma_1/\lambda_1 \tag{203}$$

rather than the Cauchy stress, σ.

4.2.7 M. Quinlan's Theory of Materials with Variable Bonding

4.2.7.1 Original Model

In developing a mathematical framework for his stress-strain law, Quinlan, in Reference 4, reasoned that since propellants consist of minute rigid particles embedded in a polymer matrix, such materials would respond to a deformation process with a change in the amount of species to species bonding. He thus proposed to correct the deficiencies of fading-memory type theories by introducing a correction term that accounted for the changes in the state of bonding that are induced by a deformation process. His constitutive model then took the form:

$$\sigma = \sigma_f + \sigma_b \tag{204}$$

in which:

σ = current stress
σ_f = fading-memory type stress
σ_b = stress correction due to change in the state of bonding

Motivated to some extent by reaction-rate theory, Quinlan modeled the evolution of the bonding state through the following ordinary differential equation:

$$\dot{\pi} = \alpha \left\{ \dot{\phi} - \mu \left[1 - e^{\nu} (\phi - \pi) \right] \right\} \tag{205}$$

subject to the initial condition:

$$\pi(0) = 1 \tag{206}$$

in which π represents the state of bonding; α, μ and ν are material parameters, and

$$\phi = 1 + \epsilon \tag{207}$$

is the stretch ratio; with ϵ, the strain.

The unique solution of (204) may be readily obtained for piecewise linear stretch histories, as reported in Reference 4.

Taking a linear viscoelastic relation for σ_f, and considering the stress correction term, σ_b, as proportional to the state of bonding, Quinlan arrived at the following stress-strain law:

$$\sigma(t) = \int_0^t G(t - \tau)\,\dot{\phi}(\tau)\,d\tau + B_o\,\dot{\pi}(t) \tag{208}$$

with:

$$G(t) = E_o\,t^{-n} \tag{209}$$

$$\dot{\pi}(t) = \alpha \left\{ \dot{\phi} - \mu \left[1 - e^{\nu(\phi - \pi)} \right] \right\} \tag{210}$$

and

$$\pi(t = 0) = 1 \tag{211}$$

The six parameters: E_o, n, B_o, α, μ and ν, needed in this theory to characterize a propellant, may be obtained by fitting the model to the observed response of the material when subjected to a saw-tooth strain history that has increasing peak strains and sufficiently long rest periods between cycles. Alternatively, the studies reported in the literature on the effects of employing different data bases for characterization, show that the test history should primarily include the maximum expected strain level, the expected range of strain rates, as well as rest and relaxation periods.

The present model was used to predict the response of TP-H1011 under several loading histories; and it reproduced, somewhat accurately, the general trend of solid propellant behavior.

In an attempt to include healing effects, the underlying assumption for the evolution of damage were revised, as explained next.

4.2.7.2 Current Model

The theory developed by Quinlan has undergone several changes; mainly in the expression defining the evolution of damage. Thus, the form:

$$\sigma(t) = \int_{0}^{t} H(t - \tau)\,\dot{\phi}(\tau)\,d\tau + C\,\dot{\pi}(t) \tag{212}$$

has been retained in all versions of this theory, but the rate mechanism underlying damage:

$$\dot{\pi} = P(\pi, \phi, \dot{\phi}) \tag{213}$$

for which:

$$\pi(\phi = 1) = 1 \tag{214}$$

was assumed to contain a neutral rate, ζ, at which damage remains constant, i.e.,

$$P(\pi, \phi, \zeta) = 0 \tag{215}$$

This concept then allowed introducing the notion that at rates higher than ζ, bond breakage would take place, while at rates smaller than the neutral rate, bond formation would ensue. The details of the derivations leading to the specific form of equation (213) are presented next.

Equation (215) for the neutral rate, ζ, may be rewritten as:

$$\begin{aligned} \zeta &= Q\ (\pi, \phi) \\ \zeta &= 0 \text{ if and only if } \pi = \phi \end{aligned} \tag{216}$$

which, upon expansion in Taylor series, becomes:

$$\zeta = Q\ (\pi,\ \pi - \phi)\Big|_{\phi = 0} + \frac{\partial Q\ (\pi,\ \pi - \phi)}{\partial(\pi - \phi)}\Big|_{\phi = 0} (\pi - \phi) + Q\ (|\pi - \phi|^2)$$

The first term on the right-hand side of this equation vanishes by virtue of (216), so that, neglecting the higher order terms, and defining:

$$\mu \overset{\text{def}}{=} \frac{\partial Q\ (\pi\ ,\pi - \phi)}{\partial(\pi - \phi)}\Big|_{\phi = 0} \tag{217}$$

leads to the following first-order expression for the neutral rate:

$$\delta = \mu(\pi - \phi) \tag{218}$$

where for bond breakage:

$$\dot{\phi} - \zeta > 0 \tag{219}$$

while for bond formation:

$$\dot{\phi} - \zeta < 0 \tag{220}$$

In addition, equation (213) may be cast in the following form:

$$\dot{\pi} = P\ (\pi, \phi\ , \dot{\phi}) = R(s,\ u) \tag{221}$$

where:

$$s = s\ (\pi, \phi)$$

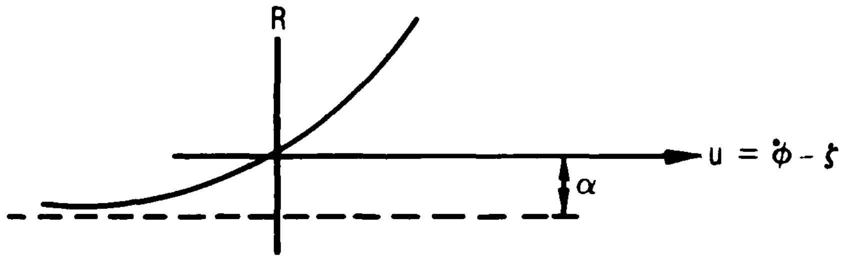
(222)

and:

$$u = \dot{\phi} - \zeta \qquad (223)$$

with ζ given by (218).

Now, under the assumption that the process of bond formation is slower than that of bond breakage, the function R defining the evolution of damage must be of the form shown in the sketch below, in which the parameter α would represent the maximum rate of bond formation.



Hence, R may be defined through the following differential equation:

$$\frac{dR(s,\ u)}{du} = \nu \left[R(s,\ u) - \alpha \right] \qquad (224)$$

where α and ν are positive constants.

Integration of (224) yields:

$$R(s,\ u) = \alpha(e^{\nu u} - 1) \qquad (225)$$

Finally, putting (218), (223), and (225) into (221), results in:

$$\dot{\pi} = \alpha \left\{ \exp\left[\nu \dot{\phi} + \mu \nu (\phi - \pi)\right] - 1 \right\} \tag{226}$$

Equations (212) and (226) subject to (214) were used by Quinlan in several ways to characterize the response of UTP-19,360B. One such stress-strain law took the following form:

$$\sigma(t) = E_o\, \epsilon(t) + \left[E_1 + E_2\, \epsilon(t)\right] \int_o^t (t - \tau)^{-n}\, \dot{\epsilon}(\tau)\, d\tau + C \dot{\pi} \tag{227}$$

in which Eo, E_1, E_2, n and C are constants and ϵ is the strain. Although some aspects of propellant behavior were better modeled than with the original version of the theory, others were not, and further revisions were necessary. In the latest version of his constitutive law, Quinlan used a Prony series to represent the relaxation function and changed strain for stretch in the original equation of evolution for damage, so that, in summary, the current model looks as follows:

$$\sigma(t) = \sigma_v(t) + \sigma_b(t)$$

$$\sigma_v(t) = G_e\, \epsilon(t) + \int_o^t G(t - \tau)\, \dot{\epsilon}(\tau)\, d\tau$$

$$G(t) = \sum_{i=1}^{n} Gi\, e^{-\tau_i t}$$

$$\sigma_b(t) = B e^{\gamma(\epsilon - \pi)}\, \epsilon(t)$$

$$\dot{\pi}(t) = \alpha \left\{ e^{\nu(\epsilon - \pi)} - 1 \right\} ;\ \pi(o) = 0 \tag{228}$$

This final version of the theory has been employed to characterize UTP-19,360B, but has not been used by Quinlan to predict the response of the propellant under any loading history other than the characterization test.

4.3 CONCLUSIONS

The best nonlinear constitutive theories available for modeling solid propellant response were selected. Each of these theories was able to model some simple constant strain rate test behavior during the early part of the program, but generally gave poor correlation with the long time complex load histories characteristic of rocket motors.

A broad nonlinear data base was developed with two solid propellants. This data was used both at CSD and at some of the University subcontractors facilities. This data base can be used for evaluating any future nonlinear constitutive theories. All data was collected on an HP-9825 computer and is available in a format for a VAX computer system.

This data was used to evaluate and further develop the nonlinear theories for solid propellant response. Each of the theories has been extensively modified and now fits both simple and complex uniaxial load histories.

These theories will be further developed for multiaxial load histories in the last phase of the program.

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Appendix A

MULTISTATION AUTOMATED DATA REDUCTION

INTRODUCTION

Automated handling of multistation tester data is accomplished with a system of interactive programs on the HP 9825 desk top computer (Figure A-137). These programs include data acquisition, stress relaxation-master modulus, straining while cooling or heating, straining to failure, and complex histories. The acquisition of data and test control are functions of the data acquisition program which supplies data to the data reduction programs. The reduction programs reduce and output data for a particular type of test history. In addition, terminal emulating software for the HP 9825 provide a data link for the transfer of data to the VAX-11 mainframe computer. This makes the data directly available to the nonlinear constitutive theory programs.

SYSTEM INSTRUMENT CONFIGURATION

The multistation data acquisition instruments are configured to provide load, crosshead position, temperature and elapsed time data to the data acquisition program. The system consists of a Hewlett Packard 9825 desk top computer, 3455 digital voltmeter, 3495 scanner, 98035 programmable clock and 9885 flexable disk drive (Figure A-138).

The HP 9825 and data acquisition program act as the system controller. The controller processes incoming test data and crosshead information and responds by sending instructions to other instruments in the system over an HP-IB interface. Output signals from the tester's load transducers, linear potentiometer, and analog thermometers are input into the scanner's programmable relay cards. The scanner's relays under command of the controller can be opened independently to route output data signals individually to the digital voltmeter where they are digitized and read by the program. Crosshead control information from output lines connected to the tester's motor-clutch assembly, is supplied to the program through the scanner in the same way as the data output signals. These

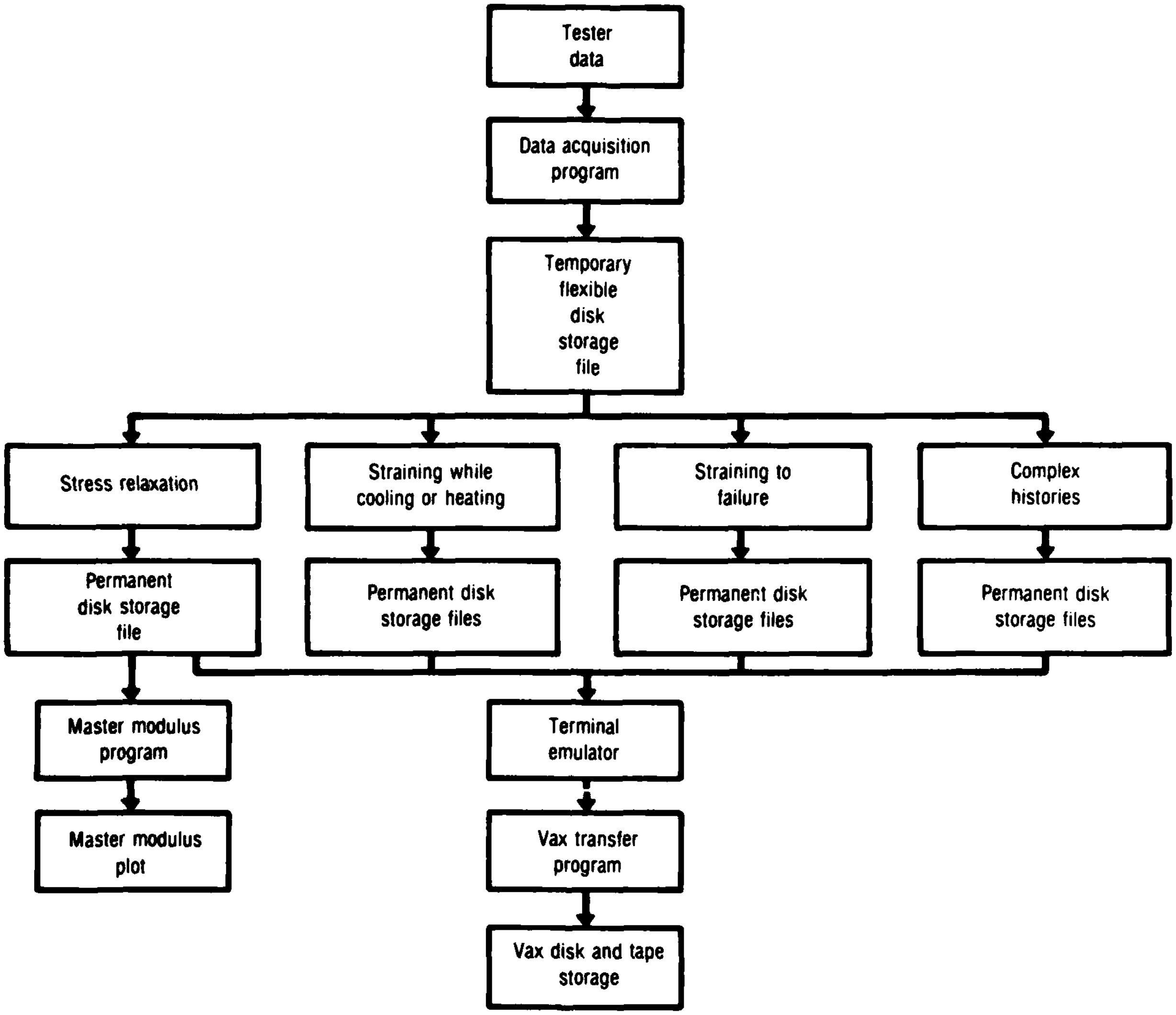


Figure A-137.

28842

signals enable the controller to react to changes in crosshead movement and direction without relying on operator intervention. The programmable clock connects directly to one of the computer's I/O ports. It provides the program with elapsed time data and a program interupt capability for controlling the rate at which data is taken. The flexible disk drive provides a mass storage medium where data is stored during testing for latter access by one of the data reduction programs.

PROGRAMS

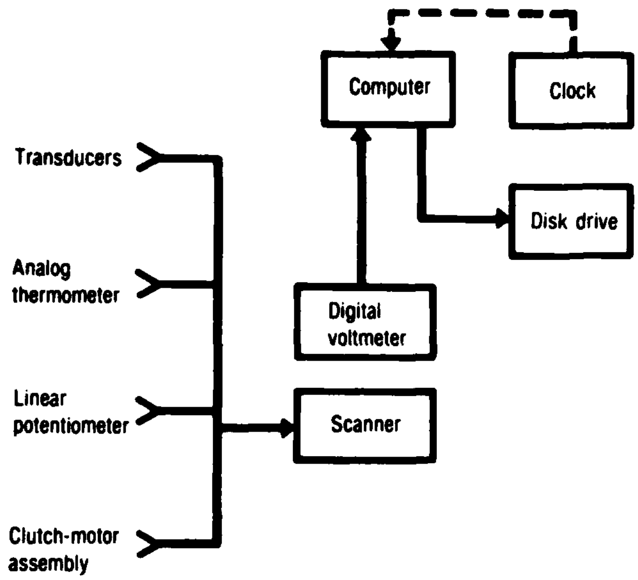


Figure A-138. 28843

Data Acquisition:

As previously stated, the data acquisition program is used to collect data from the multistation tester. Operation of the program involves steps to initialize the program, calibrate the system, and collect and store test data.

Initialization of the program is accomplished by operator entered information used to identify the particular test and define samples being tested. In response to prompts from the computer display, the operator inputs descriptions on test material, crosshead rates, strain levels, and temperature levels of the test history. Data input on the test samples include their number, gage length, and individual cross sectional areas, along with their channel locations. In addition, the operator enters pairs of crosshead rates and delta strains for each test interval used to compute sampling rates. The operator also determines how data is taken during relaxation cycles by specifying whether sampling is to be done in a fixed or log time interval.

Calibration of the system is done by an operator-interactive procedure to determine the tester's transducers and potentiometer sensitivites. This involves the operator queuing the program to take readings from the transducers at differing load conditions. By comparing the change in output signals for a known change in load, the lb/volt sensitivity of each transducer may be determined. Similarly, by moving the linear potentiometer probe a known distance its in./volt sensitivity is determined. The analog thermometers are not calibrated at the time of testing. These units output a 10 mv/^{o}F representation of the test chamber and internal sample temperature. Calibration on them is done periodically by the CSD electronics laboratory. For short time and isothermal tests, calibration is done once before testing begins. For tests

lasting over a long time period, a second calibration is done when testing is complete to enable compensation for drift in the tester's electronics. Since the load transducers are temperature sensitive, for thermal tests two calibrations must be performed at differing temperatures to determine the change in sensitivity per degree change in temperature.

When calibration is complete, the program stops operation until testing is ready to begin. On a cue from the operator, zero load and position data is taken and the system's instruments programmed to their initial conditions. The clock interupt period is set for a sampling rate determined from the initial crosshead rate and delta strain information. Scanner relays are also arranged to monitor the tester's break input voltage.

The program monitors the brake voltage until detecting the brake has disengaged which signifies crosshead motion. The clock's counter and interupt units are then started. Interupt signals are output by the clock at the set sampling rate until changed by the program at the end of the straining interval.

When interupt instructions are received from the clock, program operation branches to a data collection subroutine. The voltmeter and scanner are set to read output signals from each of the transducer, potentiometer and thermometer channels. Fifty milliseconds are required to read each channel. Elasped time, read from the clock counter, is taken as the mean time over which the data set was read. The test data is retained in a memory buffer until transferred to a disk storage file.

The program continues to monitor the crosshead break and clock information channels throughout the test. When a change in crosshead motion is detected, the clock interupt is stopped. From the test description data corresponding to the test interval, a sampling rate is determined and the clock is reset. For log time interval samplings, the clock interupt unit is stopped after each reading and the time doubled.

Up to 600 data sets may be retained in the computer's memory at one time. Data is transferred to the disk either between data set samplings, if time allows, or when testing is complete.

Data Reduction Programs:

The reduction programs reduce and output multistation data pertinent to particular types of test histories. The programs are stress relaxation-master modulus, straining while cooling or heating, straining to failure and complex histories. A description of the strain and temperature histories relevant to each is listed in Table A-35.

Test identification, calibration, load, sample extension, thermal, and time data are supplied to the programs from the acquisition data files or entered directly by the operator. In addition, relaxation cathetometer strain measurements and the thermal expansion coefficient may be optionally entered.

Each program reduces stress, strain, modulus, temperature and elapsed time data when applicable. The method by which each is determined depends on the test history and amount of information available to the program.

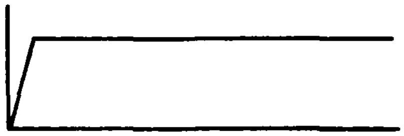
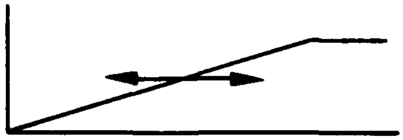
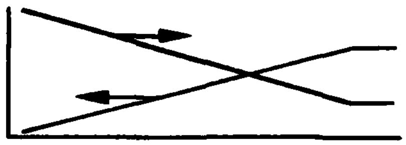
Calibration sensitivity (S) of the transducer and potentiometer are determined in general by

$$S = \text{load}/(\text{load output-zero load output})$$

where load is the transducer calibration weight or potentiometer probe displacement. For tests where multiple calibrations were performed, the sensitivities at time t are corrected for electrical drift and thermal variations with the linear relationships

$$S(t) = S_{initial} + \frac{(S_{final} - S_{initial})}{X_{final} - X_{initial}} X(t)$$

TABLE A-35

Program	Test Strain History	Output
1. Stress relaxation		Tabular - time, modulus Graphic - modulus vs time
2. Straining while cooling or heating		Tabular - time, strain, temperature, stress Graphic - stress vs time and temperature
3. Straining to failure	 	Test History - Tabular - time, strain and stress Graphic - stress vs time and straining Mech Properties Tabular - initial modulus, maximum stress and strain - corrected stress and strain - rupture strain
4. Complex histories	Combination of straining, relaxation and temperature intervals	Tabular - time, strain temperature and stress Graphic - stress vs time and strain and temperature vs time

where X is time for isothermal and temperature for nonisothermal tests. Temperature corrections are not made on the potentiometer sensitivity since it is located outside the enviromental test chamber.

Zero load outputs (ZO) for the transducers are also corrected for electrical drift and thermal variation by the same method as the sensitivities.

Corrections on the zero position output of the potentiometer cannot be made since the crosshead can't be accurately returned to its initial position.

Sample stresses (σ) at time t are calculated by

$$\sigma(t) = \left[\text{transducer output} - \text{ZO}\ (t)\right] S(t)/\text{cross-sectional area}$$

Sample strain (ϵ) at time t is determined by

$$\epsilon(t) = \left[\text{pot output} - \text{ZO}\right] S(t)/\text{gage length}$$

For nonisothermal tests a strain correction may be applied using the thermal expansion coefficient (α). In this case, the total sample strain becomes

$$\epsilon(t) = \text{mechanical strain} + \left[T(t) - T_{\text{initial}}\right] \alpha/\text{gage length}$$

An additional correction for effective gage length may be made using cathetometer measurements of actual sample strains. The correction factor is determined as the ratio of the mean intervals in the test history. For histories where multiple cathetometer measurements were made, the correction factors are linearized to measured strain between them.

Relaxation and secant modulus (E) at time t is determined by

$$E(t) = \sigma(t)\left[1 + \epsilon(t)\ /\epsilon(t)\right]$$

where $\epsilon(t)$ is held constant over relaxation test intervals.

Temperature is reduced from analog thermometer readings by converting the millivolt output to volts.

Elapsed time is calculated as the difference between when the data was taken and when initial loading occurred (t_o) since loading times may vary from sample to sample, t_o is approximated by the time of initial straining.

Once data is reduced, a tabular and graphic summary of the test is output by each program. A description of the outputs is listed in Table A-35. To

retain data for future reference and reuse, identification, calibration and raw test data are stored on permanent diskette data files.

Terminal Emulator

The program is used to transfer data between the HP 9825 and VAX-11, desk top and mainframe computers.

A link is created between the computer types utilizing the VAX-11's dial-in lines and an RS-232 interface which connects the 9825 to an acoustic coupler. The emulator software then supplies the capability of using the 9825 as an intelligent terminal through which data may be read from the flexible disks and sent over phone lines to the VAX.

Data transfer is accomplished with a VAX program which reads data sent from the terminal and retains it in storage files for access by the nonlinear theory programs.

SYMBOLS

A_c	microcrack growth rate shift factor
A_F	temperature dependent material function
A_{ij}	expansion coefficients of bulk stress in terms of octahedral strains
A_n	constant
A_o	initial area
A_T	temperature shift factor (a_T)
$a\,\eta$	(AHETA) damage related shift function
a	half sample width
a_F	softening function
a_k	constant
a_{np}	expansion coefficients of correction modulus
A1, A2, A3, A4, A6, Ai	constants
2a	biaxial sample width
B	Cauchy-green deformation tensor
B	bulk modulus and a constant
B'	deviatoric deformation tensor
2b	biaxial sample height (gage length)
C	softening function
CSD	Chemical Systems Division
C_x	rehealing parameter
c	constant
C, C_1, C_2, C_i	constants

d	constant
D_m, D_5, D_6, D_7	constants
E	modulus
E_e	equilibrium modulus
E_R	reference modulus and normalized coefficient for modulus
E_R	relaxation modulus
$E(t)$, $E_{rel}(t)$	linear viscoelastic relaxation modulus
e	product of F and virgin response function g
e_{ij}	deviatoric strain tensor
$E(\xi)$	linear viscoelastic modulus
F	force
$F(t)$	constant rate modulus
$F(\xi, \epsilon_m)$	damage curve at ϵ_m damage level
f	material parameter
(f)	deformation function
f_c	constant time rate of change of deformation invariant
$f(t)$	viscoelastic type function
^oF	degrees Fahrenheit
F	damage function or softening function
F	strain magnification factor
G	shear modulus
G. L.	gage length
G_c	corrected modulus
G_r	relaxation modulus

G_{rel}	shear relaxation modulus
$G(t)$	shear relaxation modulus
g	virgin response function
$g(\ )$	function of
(g)	strain softening function
h	function of damage in kinetic equation of evolution
HTPB	Hydroxy Terminated Polybutadiene
I_d	volume dilatation
I_n	contribution to stress at time t_n
$I\gamma$	octahedral shear strain
$\lVert I\gamma \rVert_{pi}$	L_p norm
J	creep function
JANNAF	Joint Army Navy NASA Air Force
K	constant
K_I	stress intensity factor
K_x	rehealing parameter
k	constant
L_x	constant
M	constant
M_x, M_2, M_4	constants
m	constant
mv	millivolts
m, m_2, m_4	material parameters

N	number of cycles
n	constant
P	terms of equation under summation
P	hydrostatic pressure
PBAN	Polybutadiene Acrylonitrile
p	constant
P_2, P_4	constants
P_{15}	used to normalize Y_3 to 1
Q	terms of equation under summation
q	constant
RH	relative humidity
S	virgin stress and damage parameter constant
S_ℓ	damage parameter
S_o	constant
S_r	certain measure of damage
$S_t - S_\tau$	temperature shifted time
S_x	constant
$\mathcal{S}$	damage parameter
T	temperature
T	peak stress time
T_a	material property and shift temperature
T_o	temperature at $t = 0$
T_R	reference temperature

t	time
t_n	time
t_o^*	time to failure under constant load
UTP	United Technologies Propellant
x	$\equiv \epsilon/\epsilon_m$
X	width position from center of biaxial sheet
X_r	root of Y_3
y	$\equiv e_{ij}$
Y_i, Y_1, Y_2, Y_3	functions related to damage
α	coefficient of thermal expansion
α	constant
β	constant
β	parameter
γ	shear strain
ΔL	change in length
δ_{ij}	Kronecker delta
ϵ	strain
ϵ_1	principal strain
ϵ_2	lateral strain
ϵ_{11}, ϵ_{22}, ϵ_{33}	principal strains
ϵ^o	pseudo strain
ϵ_m, ϵ_{max}	maximum strain
$\epsilon(t)$	strain at time t
ϵ_u	strain of unfilled polymer
ϵ_σ	strain due to mechanical stress

η	compressibility (η = 0 is incompressibility)
$\eta(t)$	related to damage function,
λ	extension ratio ($1 + \epsilon$)
λ	healing correction factor
λ	softening function
λ	width to height ratio
ξ	reduced time
ξ	ratio of position to half sample
ξ	width (x/a)
π_α	second invariant of tension ($\alpha = \sigma, B$)
$\sum$	summation
σ	engineering stress or stress
σ	Cauchy-stress tensor
σ_B	bulk stress
σ_c	stress correction
σ_{ij}^d	deviatoric stress
σ'	deviatoric stress
σ_ℓ	linear viscoelastic stress
σ_o	constant stress
σ_{kk}	bulk stress
σ_r	linear viscoelastic stress
$\sigma(t)$	stress at time t
$\sigma_f(t)$	fading memory stress
τ	reduced time
τ	shear stress

τ	shifted time
ϕ	function of loading
Ψ_n	nth component of stress correction
ω	normalized damage function
II_α	second invariant of tensor ($\alpha = \sigma$, B)
$\sqrt{II_{B'}}$	second invariant of deformation tensor
$\sqrt{II_{\sigma'}}$	second invariant of deviatoric stress
$\lvert\cdot\rvert$	denotes absolute value